MA/Start: Specifying Training and Instruction Requirements using Morphological Analysis

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Abstract – **Training and instruction (T&I) is increasingly based on advanced learning tools such as e-learning, simulators and virtual environments. In order to utilise these tools in an effective way, a first set of global requirements for T&I programs should be specified in order to identify appropriate needs and effective instructional methods. General Morphological Analysis (GMA) is a non-quantified modelling method for structuring and analyzing the total set of relationships in complex social, organizational and educational problem fields. GMA has been employed to develop a generic inference model for specifying T&I needs at an early stage, and identifying the relationships between needs and means. This article gives a background to GMA, its application to the development of T&I programs, and an example of a generic model for identifying alternative T&I requirements for a specific case.**

Index Terms – **Instructional Design, Morphological analysis, Training & Instruction Requirements**

I. INTRODUCTION

Training and instruction (T&I) programs are increasingly based on advanced learning tools such as e-learning, simulators and virtual environments. Such tools are, in turn, becoming increasingly complex and have uncertain consequences for T&I design, especially at the beginning of the procurement track when there is still a good deal of uncertainty about user specifications, technical feasibility and cost. In this context, what is needed is a general method for specifying a first set of global requirements for T&I programs in order to identify and develop appropriate instructional methods and learning tools.

However, this presents us with a number difficult of methodological problems. Firstly, many of the factors involved are non-quantifiable, since they contain a mix of technical, organizational and pedagogical factors. Secondly, the relationships between these factors may involve thousands or even hundreds of thousands of alternatives – far too many to inspect by hand. Finally, the very process by which T&I programs are designed and developed is often difficult to trace – i.e. we seldom have an adequate “audit trail” describing how relevant parameters are identified and how these parameters are related to each other. Without some form of *transparency* and *traceability* we have little possibility of scientific control over results.

In the early 2000s, the Netherlands Organisation for Applied Scientific Research (TNO) developed a method for designing *needs statements* for T&I programs called SLIM (Specifying Learning means in an Iterative Manner). The method is directed towards the first phase of the instructional design process:

> “The SLIM method proposes to involve all stakeholders from the beginning in a series of workshops under the guidance of experienced instructional designers. These instructional designers ensure that specifications are designed in a systematic, iterative, way based on instructional design and development models. The workshop participants, however, bring in all the necessary information and they take all the decisions. The SLIM method is geared towards the first phase of the instructional design process: designing a needs statement in the form of a first set of global user requirements.” [1] (Abstract).

SLIM is based on six principles. The design of instructional products

1. is an iterative process.
2. should be done in a systematic way.
3. should be based on learning needs.
4. should deal with uncertainty and make assumptions explicit.
5. should reuse information by recording product and process information.
6. should involve all stakeholders from the beginning.

SLIM has been carried out “by hand” or only with rudimentary computer support. Dedicated computer support would make it possible to interactively represent needs and requirements from different perspectives (such as content, organisation and costs) and to balance different stakeholder interests (e.g. purchaser, producer and users).

General Morphological Analysis (GMA) is a computer-aided modelling method for structuring and analyzing the total set of relationships within complex social, organizational and educational problem fields [11][14]. Developed at the Swedish Defence Research Agency (FOI - Totalförsvarets Forskningsinstitut) in the middle of the 1990s, it can be used to create non-quantified ("what-if") inference models for generating scenarios, defining and analyzing complex policy spaces and relating ends and means in strategic planning.

In 2005, FOI and TNO collaborated in a project to see if GMA could be utilised to facilitate SLIM in a more efficient and systematic way, both in order to save time and resources, and to enhance traceability, transparency and accountability. The initial, computer-aided system thus developed was called "SLIM powered by MA". **MA/Start** (Specifying Training and Instruction Requirements) is a further development of this concept.

This article begins with a short historical and methodological background to General Morphological Analysis (GMA), describes its application to the development of a generic T&I specification model, and gives an example of such a model for identifying alternative T&I designs for a specific case.

II. METHODOLOGICAL BACKGROUND

In the early 1990's, a research program was initiated at the Swedish Defence Research Agency (FOI) aimed at developing a methodological framework for modelling systems and processes, which cannot be meaningfully quantified. We began by attempting to develop an extended form of what is called *typology analysis* [2]. Initially, we thought we were doing something new. However, we subsequently learned that extended typology analysis was invented as early as the 1940's by Professor Fritz Zwicky at the California Institute of Technology in Pasadena. He called it the *morphological approach.*

The term *morphology* derives from antique Greek (*morphē*) which means *shape* or *form*. The general definition of morphology is "the study of form or pattern", i.e. the shape and arrangement of parts of an object, and how these *conform* to create a *whole* or Gestalt. The "objects" in question can be physical (e.g. an organism or an ecology), social/organizational (e.g. a corporation or a social institution), or mental (e.g. linguistic forms or any system of ideas).

The first to use the term *morphology* as an explicitly defined scientific method would seem to be J.W. von Goethe (1749-1832), especially in his "comparative morphology" in botany. Today, morphology is associated with a number of scientific disciplines where *formal structure*, and not necessarily function or quantity, is a central issue, e.g. linguistics, geology and zoology.

Zwicky proposed a *generalized form of morphology*, which today goes under the name of General Morphological Analysis (GMA)

> "Attention has been called to the fact that the term *morphology* has long been used in many fields of science to designate research on structural interrelations – for instance in anatomy, geology, botany and biology. ... I have proposed to generalize and systematize the concept of morphological research and include not only the study of the shapes of geometrical, geological, biological, and generally material structures, but also to study the more abstract structural interrelations among phenomena, concepts, and ideas, whatever their character might be." [3] (p. 34).

Zwicky developed GMA as a method for structuring and investigating the total set of relationships contained in multi-dimensional, non-quantifiable, problem complexes [3][4]. He applied the method to such diverse fields as the classification of astrophysical objects, the development of jet and rocket propulsion systems, and the legal aspects of space travel and colonization. He founded the Society for Morphological Research and championed the "morphological approach" from the 1940's until his death in 1974.

More recently, morphological analysis has been applied by a number of researchers in the USA and Europe in the fields of policy analysis and futures studies [5][6][7]. In 1995, advanced computer support for GMA was developed at FOI [8]. This has made it possible to create non-quantified inference models, which significantly extends GMA's functionality and areas of application [9][10][11][12][13][14]. Since then, some 80 projects have been carried out using computer aided GMA, for structuring complex policy and planning issues, developing scenario and strategy laboratories, and analyzing organizational and stakeholder structures.

Essentially, GMA is a method for identifying and investigating the total set of possible relationships or "configurations" contained in a given problem complex. This is accomplished by going through a number of iterative phases which represent cycles of analysis and synthesis – the basic method for developing (scientific) models [15].

Parameter A	Parameter B	Parameter C	Parameter D	Parameter E	Parameter F
Condition A1	Condition B1	Condition C1	Condition D1	Condition E1	Condition F1
Condition A2	Condition B2	Condition C2	Condition D2	Condition E2	Condition F2
Condition A3	Condition B3	Condition C3	Condition D3	Condition E3	Condition F3
Condition A4		Condition C4	Condition D4		Condition F4
Condition A5			Condition D5		
			Condition D6		

Figure 1: A 6-parameter morphological field. The darkened cells define one of 4320 possible (formal) configurations.

The method begins by identifying and defining the most important dimensions (or *parameters*) of the problem complex to be investigated, and assigning each dimension a range of relevant *values* or *conditions*. This is done mainly in natural language, although abstract labels and scales can be utilized to specify the set of elements defining the discrete *value range* of a parameter.

A morphological field is constructed by setting the parameters against each other to create an n-dimensional configuration space (Figure 1). A particular *configuration* (the darkened cells in the matrix) within this space contains one ”value” from *each* of the parameters, and thus marks out a particular state of, or possible formal solution to, the problem complex.

The point is, to examine all of the configurations in the field, in order to establish which of them are possible, viable, practical, interesting, etc., and which are not. In doing this, we mark out in the field a relevant *solution space*. The solution space of a Zwickian morphological field consists of the subset of all the configurations which satisfy some criteria. The primary criterion is that of internal consistency.

Obviously, in fields containing more than a handful of variables, it would be time-consuming – if not practically impossible – to examine all of the configurations involved. For instance, a 6-parameter field with 6 conditions under each parameter contains more than 46,000 possible configurations. Even this is a relatively small field compared to the ones we have been applying.

Thus the next step in the analysis-synthesis process is to examine the *internal relationships* between the field parameters and "reduce" the field by weeding out configurations which contain mutually contradictory conditions. In this way, we create a preliminary outcome or solution space within the morphological field without having first to consider all of the configurations as such.

This is achieved by a process of *cross-consistency assessment* (CCA). All of the parameter values in the morphological field are compared with one another, pair-wise, in the manner of a cross-impact matrix (Figure 2). As each pair of conditions is examined, a judgment is made as to whether – or to what extent – the pair can coexist, i.e. represent a consistent relationship. Note that there is no reference here to direction or causality, but only to mutual consistency. Using this technique, a typical morphological field can be reduced by up to 90 or even 99%, depending on the problem structure.

There are two principal types of inconsistencies involved here: purely *logical* contradictions (i.e. those based on the nature of the concepts involved); and *empirical* constraints (i.e. relationships judged be highly improbable or implausible on empirical grounds). *Normative* constraints can also be applied, although these must be used with great care, and clearly designated as such.

		Parameter A					Paramete			Parameter C				Parameter D						Paramete		
		Condition A1	Condition A2	Condition A3	Condition A4	Condition A5	Condition B1	Condition B2	Condition B3	Condition C1	Condition C2	Condition C3	Condition C4	Condition D1	Condition D2	Condition D3	Condition D4	Condition D5	Condition D6	Condition E1	Condition E2	Condition E3
Parameter B	Condition B1																					
	Condition B2																					
	Condition B3																					
Parameter C	Condition C1																					
	Condition C2																					
	Condition C3																					
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Parameter D	Condition D1																					
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	Condition D6																					
Parameter E	Condition E1																					
	Condition E2																					
	Condition E3																					
Parameter F	Condition F1																					
	Condition F2																					
	Condition F3																					
	Condition F4																					

Figure 2: The cross-consistency matrix for the morphological field in Figure 1.

This technique of using pair-wise consistency assessments between conditions, in order to weed out internally inconsistent configurations, is made possible by a principle of dimensionally inherent in morphological fields, or any discrete configuration space. While the number of configurations in such a space grows exponentially with each new parameter, the number of *pair-wise relationships between parameter conditions* grows only in proportion to the triangular number series – a quadratic polynomial. Naturally, there are also practical limits reached with quadratic growth. The point, however, is that a morphological field involving as many as 100,000 formal configurations can require no more than few hundred pair-wise evaluations in order to create a solution space.

When this solution (or outcome) space is synthesized, the resultant morphological field becomes an *inference model*, in which any parameter (or multiple parameters) can be selected as "input", and any others as "output". Thus, with dedicated computer support, the field can be turned into a laboratory with which one can designate initial conditions and examine alternative solutions.

GMA seeks to be integrative and to help discover new relationships or configurations. Importantly, it encourages the identification and investigation of boundary conditions, i.e. the limits and extremes of different parameters within the problem space. The method also has definite advantages for scientific communication and – notably – for group work. As a process, the method demands that parameters, conditions and the issues underlying these be clearly defined. Poorly defined concepts become immediately evident when they are cross-referenced and assessed for internal consistency. Like most methods dealing with complex social and organizational systems, GMA requires strong, experienced facilitation, an engaged group of subject specialists and a good deal of patience.

III. A GENERIC MODEL FOR DEVELOPING NEEDS REQUIREMENTS FOR T&I PROGRAMS

MA/Start is carried out in facilitated groups of 6-8 (subject specialist) stakeholders. Stockholder interaction is a central feature of the process, since we are not only structuring a complex problem, but creating among stakeholders shared concepts and a common modelling framework. The process takes 1-2 days. Virtually all of the work is done in the workshop setting, with little back-office or software preparation time required. Also, the software is designed to facilitate project documentation during the workshop sessions themselves. The models that are generated during these sessions belong to the client, who is provided with software and documentation to run and maintain them.

The four overriding steps in the SLIM process concern the following:

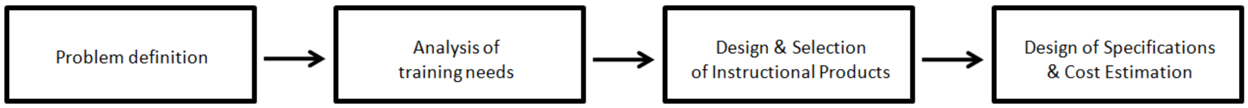


Figure 3: Four steps in SLIM [1], p. 327

MA/Start is primarily concerned with the areas of *Analysis of Training Needs* and *Design & Selection of Instructional Products*. It is here that one must identify and relate different tasks and functions, training goals and activities, and types of instruction and instructional products.

The generic T&I development model employs the following seven (start) parameters:

- Tasks to be learned
- Learning goals
- Learning activities
- Instructional directives
- Type of feedback required
- Learning method
- Learning means

(The model is not restricted to these parameters. For instance, target groups, user requirements and cost constraints can be added. The modelling group makes the decision to expand the base model to incorporate additional relevant parameters.)

Figure 4 is the (generic) morphological field that is initially presented to the stakeholder group that will carry out the modelling process. It presents the seven pre-defined *parameter heads* in an otherwise empty morphological field. It is the task of the stakeholder modelling group (facilitated by a trained morphologist) to fill in the relevant value-ranges for each of the parameters – in accordance with the alternatives available (or imaginable) for the T&I program at hand.

A simple (hypothetical) training model was produced during the FOI/TNO collaboration in order to test the feasibility of the MA/SLIM concept. For this model, we defined a single *task*: "to learn to write a report or article". Sample value ranges for the other six parameters pertaining to this task are shown in Figure 5. (Note, that even this relatively small morphological field contains 5,760 possible "configurations".)

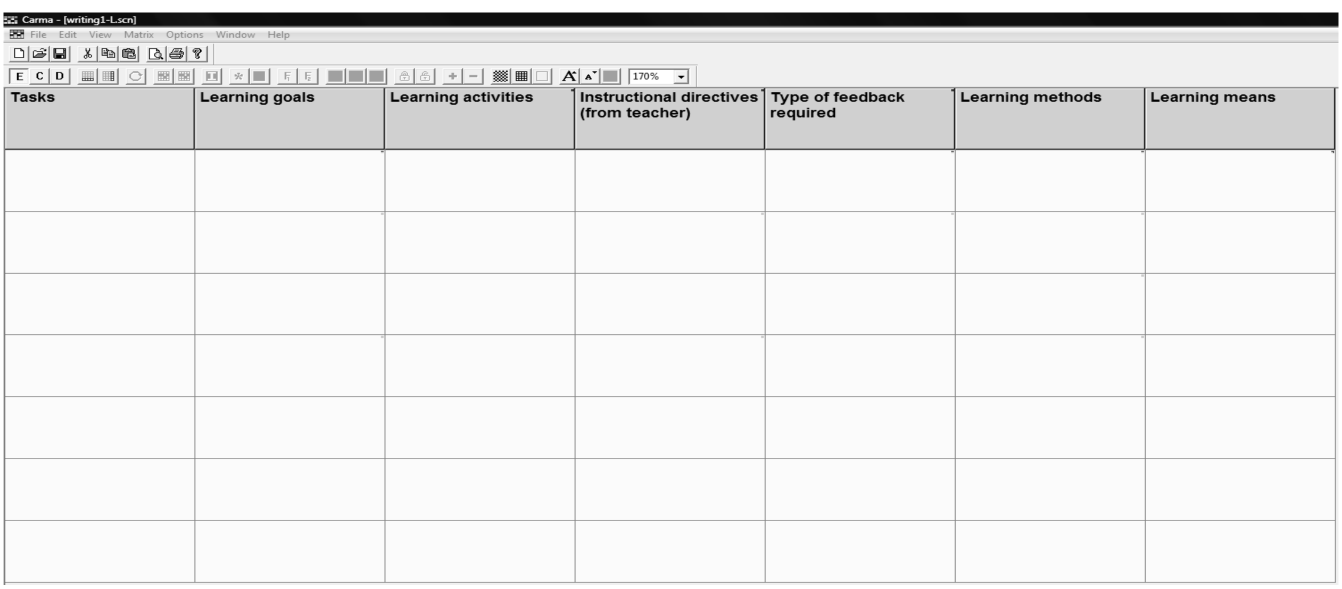
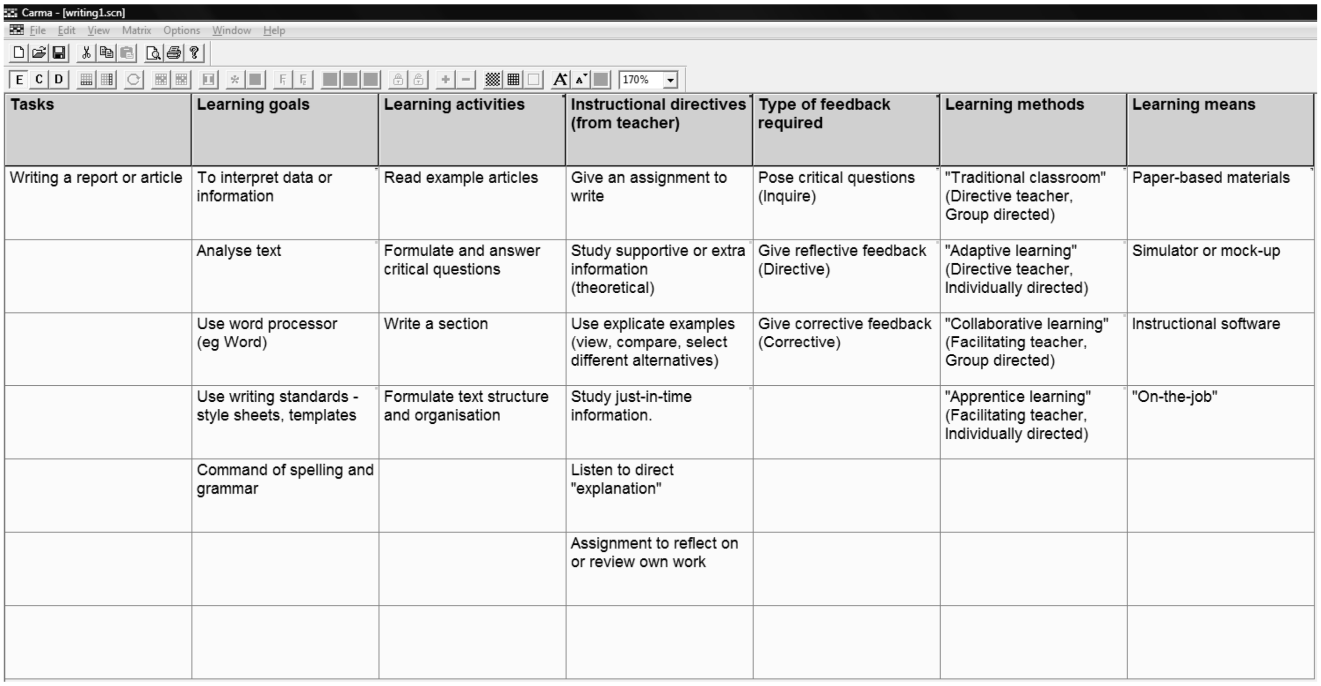


Figure 4: Generic T&I specification template



Tasks	Learning goals	Learning activities	Instructional directives (from teacher)	Type of feedback required	Learning methods	Learning means
Writing a report or article	To interpret data or information	Read example articles	Give an assignment to write	Pose critical questions (Inquire)	"Traditional classroom" (Directive teacher, Group directed)	Paper-based materials
	Analyse text	Formulate and answer critical questions	Study supportive or extra information (theoretical)	Give reflective feedback (Directive)	"Adaptive learning" (Directive teacher, Individually directed)	Simulator or mock-up
	Use word processor (eg Word)	Write a section	Use explicate examples (view, compare, select different alternatives)	Give corrective feedback (Corrective)	"Collaborative learning" (Facilitating teacher, Group directed)	Instructional software
	Use writing standards - style sheets, templates	Formulate text structure and organisation	Study just-in-time information.		"Apprentice learning" (Facilitating teacher, Individually directed)	"On-the-job"
	Command of spelling and grammar		Listen to direct "explanation"			
			Assignment to reflect on or review own work			

Figure 5: Prototype T&I development model for "Writing a report or article".

The next step in the modelling process is to establish the relationships, or more specifically, the *dependencies* between these parameters. The number of dyadic (pair-wise) relationships between a set of factors N is:

$$\frac{N(N-1)}{2}$$

Since there are seven parameters involved, there are 21 dyadic relationships and, thus, 21 *possible* dependencies. A careful examination of these revealed that there are seven principle dependencies for consideration. (That this is the same number as the number of parameters is purely coincidental.)

The dependencies are shown in Figure 6. (A → B reads: B is dependent on A.)

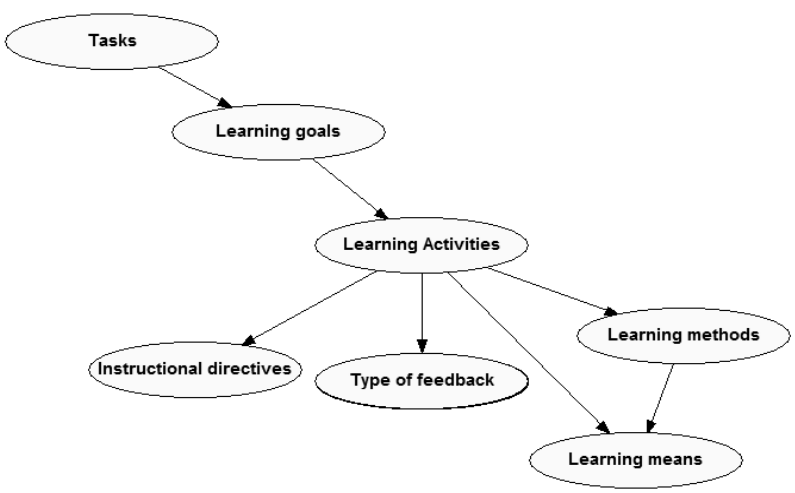


Figure 6. Dependencies between the seven parameters in the T&I development model

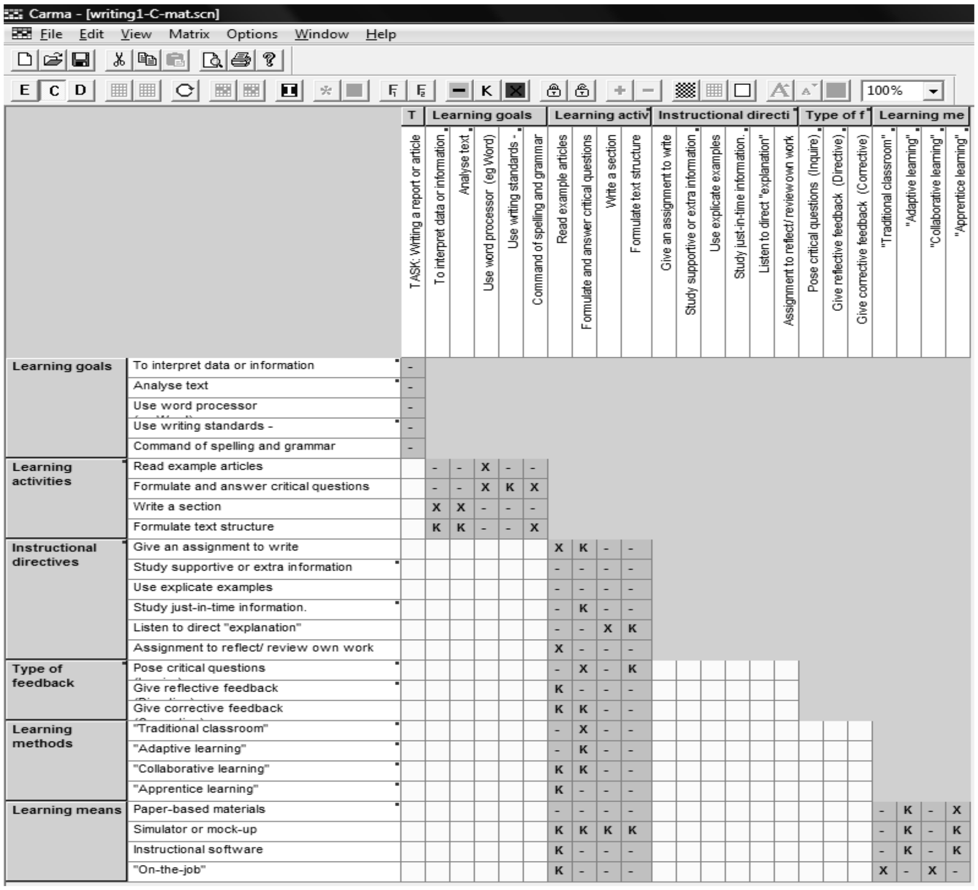


Figure 7: Cross-Consistency Assessments (CCA) showing the seven interdependent parameters. (The shaded areas represent the areas of dependency.)

Three assessment keys were used:

"—" = This pair of conditions is possible and fully appropriate/optimal

"K" = This pair of conditions if possible but not optimal

"X" = This pair of conditions is not possible or highly inappropriate

Two examples from the model, complied on the basis of these assessments, are shown in Figures 8 and 9. (Note: On the computer, morphological field configurations are colour-coded. For instance, selected input conditions are rendered in red, and output conditions in blue. In the figures below, red is represented by grey, and blue is represented by black.

The grey cells represent user-selected "input" conditions and the black cells represent possible or appropriate "output" or solutions. In Figure 8, the user is employing the model "prescriptively": given the designate tasks, goals and learning activities (grey), what instructional directives, types of feedback, learning methods and means are possible and most appropriate? In Figure 9, the user is employing the model "diagnostically": given an example of instructional directives and learning methods and means, what types of learning goals and activities would this support.

It is important to note that it is the *process of developing the model* which is at least as important as the resultant model itself. It is this process which creates a common understanding of the T&I problem complex among stakeholders. Nor should the model be seen as giving an "absolute answer". Models such as these are exploratory: they give decision support by synthesising a manageable solution space out of a large and complex problem space.

The T&I model presented here was developed solely for the purpose of demonstrating the feasibility of the **MA/Start** concept.

Carma - [writing1-L.scn]

Tasks	Learning goals	Learning activities	Instructional directives (from teacher)	Type of feedback required	Learning methods	Learning means
Writing a report or article	To interpret data or information	Read example articles	Give an assignment to write	Pose critical questions (Inquire)	"Traditional classroom" (Directive teacher, Group directed)	Paper-based materials
	Analyse text	Formulate and answer critical questions	Study supportive or extra information (theoretical)	Give reflective feedback (Directive)	"Adaptive learning" (Directive teacher, Individually directed)	Simulator or mock-up
	Use word processor (eg Word)	Write a section	Use explicate examples (view, compare, select different alternatives)	Give corrective feedback (Corrective)	"Collaborative learning" (Facilitating teacher, Group directed)	Instructional software
	Use writing standards - style sheets, templates	Formulate text structure and organisation	Study just-in-time information.		"Apprentice learning" (Facilitating teacher, Individually directed)	"On-the-job"
	Command of spelling and grammar		Listen to direct "explanation"			
			Assignment to reflect on or review own work			

Figure 8: From a prescriptive point of view

Carma - [writing1-L.scn]

Tasks	Learning goals	Learning activities	Instructional directives (from teacher)	Type of feedback required	Learning methods	Learning means
Writing a report or article	To interpret data or information	Read example articles	Give an assignment to write	Pose critical questions (Inquire)	"Traditional classroom" (Directive teacher, Group directed)	Paper-based materials
	Analyse text	Formulate and answer critical questions	Study supportive or extra information (theoretical)	Give reflective feedback (Directive)	"Adaptive learning" (Directive teacher, Individually directed)	Simulator or mock-up
	Use word processor (eg Word)	Write a section	Use explicate examples (view, compare, select different alternatives)	Give corrective feedback (Corrective)	"Collaborative learning" (Facilitating teacher, Group directed)	Instructional software
	Use writing standards - style sheets, templates	Formulate text structure and organisation	Study just-in-time information.		"Apprentice learning" (Facilitating teacher, Individually directed)	"On-the-job"
	Command of spelling and grammar		Listen to direct "explanation"			
			Assignment to reflect on or review own work			

Figure 9: From a diagnostic point of view

IV. CONCLUSIONS

MA/Start enables developers to go through a T&I requirement specification process in a highly structured, iterative manner. Supported by computer-aided General Morphological Analysis (GMA), the process helps stakeholders to analyse and visualise the various factors involved in T&I development, giving insight into the consistency and consequences of different possible choices. These choices may involve (educational) content, (organisational) form and financing, each with its own separate visualisation. The method also provides the facility to *record* and *trace* the requirements specification *process*, including decisions taken, in order to enhance *transparency* and *accountability* and to gain insight into the effects of possible changes during the process.

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