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# Developing an input–output activity matrix (IOAM) for environmental and economic analysis of manufacturing systems and logistics chains

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ABSTRACT

An activity matrix (AM) shows the activities that transform an organization's inputs into outputs. The inputs are the system targets and the materials, energy and other resources that are used to achieve these. The outputs are the system performance expressed in terms of production, quality, profit, environmental performance, waste, etc. Performance may be measured against the financial, environmental, technical, social or other system targets.

A concurrent enterprise view is used to represent the manufacturing system activities and the paper examines how an AM may be used to represent and design systems. Two kinds of AM are examined; an unconstrained activity matrix and an input–output activity matrix (IOAM). With an unconstrained AM, the system designer chooses system outputs (attributes or requirements) intuitively. This provides great flexibility and allows e.g. the social and organisational implications of proposed changes to be investigated. The inputs are not formally stated. Although a systems designer normally focuses on identifying the stages of a product life cycle and analysing their impact on the system's outputs, the main emphasis of the paper is on the IOAM and its use to represent the transformation of an organization's inputs into outputs. The input–output representation developed in the paper is used to examine manufacturing and logistics systems. First, the IOAM is used to represent a manufacturing system (as one tier of a logistics chain) and its performance. Secondly, the IOAM representations may be derived for a multi-tier system to represent its production, economic and environmental performance.



## 1. Manufacturing systems design, the unconstrained activity matrix and applications

Manufacturing systems design aims to create manufacturing systems that perform well. Usually, this is achieved by improving the performance of an existing manufacturing system. An activity matrix (AM) is a succinct way to represent the activities of a manufacturing system and how these activities influence the company's performance expressed in terms of its attributes. The paper assumes that concurrency and integration are desirable.

The paper first describes an unconstrained AM, where the system outputs (attributes or requirements) are chosen by the systems designer. The representation is very flexible and the inputs are not normally stated. The original AM used the structured analysis representation of a concurrent manufacturing system developed as part of the EU IDEA project, described in Bonney et al. (2000), which schematically showed the relationships between the different stages of product design, systems design and manufacture. Using structured analysis conventions, the context diagram is decomposed hierarchically into a set of structured boxes that convert inputs into outputs using mechanisms under control. Fig. 1 shows a structured analysis representation expressed as an input–output model where the controls and constraints are also viewed as inputs.

The concurrent manufacturing systems design context uses the following life cycle stages:

- A1 Determine the system requirements
- A2 Product design
- A3 Process design
- A4 Workplace design
- A5 Manufacturing system design
- A6 System implementation
- A7 System operation
- A8 Analysis of system performance

The structured representation shown in Figs. 2 and 3 and the AM shown in Table 1 use the life cycle stages A2–A7 as column

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headings. Each column heading is sub-divided into individual system steps to the level of detail required for analysis. Subsequent changes to the system representation could flag a requirement for activity changes and vice versa. Unconstrained AMs do not show the system inputs; namely the plans that the system is aiming to achieve and the resources used by the manufacturing system such as the finance, materials and people.

With a structured system or its equivalent AM representation, the system designer chooses a level of detail appropriate for the specific study. The AM shows:

- The life cycle stages on the horizontal axis.
- Outputs, attributes or system requirements on the vertical axis that are of three kinds: essential, desirable and 'other'. These may be described broadly as 'systems designer's choices' (e.g., Chen et al., 2001).
- Activities in the matrix cells. These activities are the processes performed at each life cycle stage; they contribute to the attributes performance.

The unconstrained AM representation described does not choose the system inputs, nor state how to choose system activities and system outputs, which include system attributes and performance measures. These choices are left to the systems investigator. The lack of restrictions means that attribute selection is very flexible and allows an analyst to choose any focus; indeed, for exploratory and explanatory reasons, our early work and Table 1 emphasised characteristics such as responsiveness and organisational requirements rather than physical outputs. Table 1 is a typical unconstrained

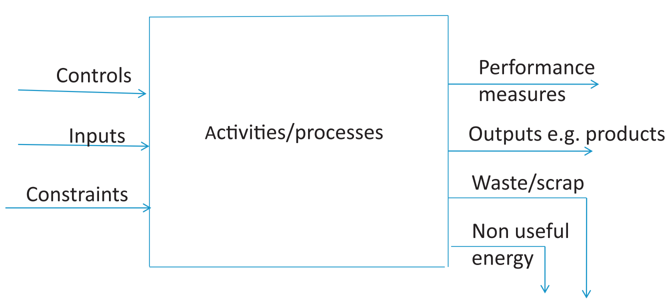


**Fig. 1.** A structured representation shown as an input–output model.

Activity Matrix representing the integrated manufacturing system that is being considered. The system requirements column lists a selection of the essential and desirable attributes. Obvious omissions include generic factors such as 'health and safety', an essential characteristic of any product, system or process, and 'environmental requirements', an attribute of increasing importance. Another desirable, frequently essential, requirement is investment appraisal of the proposed activities. The system design process chooses activities to satisfy the requirements 'as well as possible'. It will be seen that some listed items e.g. organisational requirements (row 4), administrative actions, quantitative analysis and behavioural analysis rows (rows 7, 8 and 9), are so generic that they could encourage a wide range of views about which activities to consider. For example, a behavioural emphasis could encourage a designer to consider and improve understanding of human-centred aspects of scheduling within production planning and control (PPC) or to consider operator comfort when designing workplaces (MacCarthy and Wilson, 2001).

To design systems, it is frequently important and useful to identify and overcome omissions. In principle therefore, an investigation should consider as many alternatives as possible and seek to identify new options. Ways to do this include: completely systematising the investigation e.g. using structured analysis; using input–output analysis to examine the relation between specific inputs and outputs; considering how techniques, e.g. computer aided design (CAD) and investment appraisal, could be used at key stages of product introduction such as concept design, detailed design, process planning, etc (Pahl and Beitz, 2007) to help to identify a range of solutions, sometimes to problems that otherwise might not be recognised. Thus, the early availability of a realistic visual representation of a product (e.g., using CAD) could clarify how the product could be used, could help to identify user problems and suggest other design possibilities and could be used as a tool to market the concept and the finished product (Bochenek et al., 2001). On the other hand, investment appraisal techniques can help to prioritise actions and limit consideration of potentially unrewarding investigations. For example, by considering the lead time and resource implications of investing in a specific PPC system to plan and control manufacturing, a simple model could calculate the investment consequences of placing specific loads on the company's resources (e.g., Anderson et al., 1989). The model could then

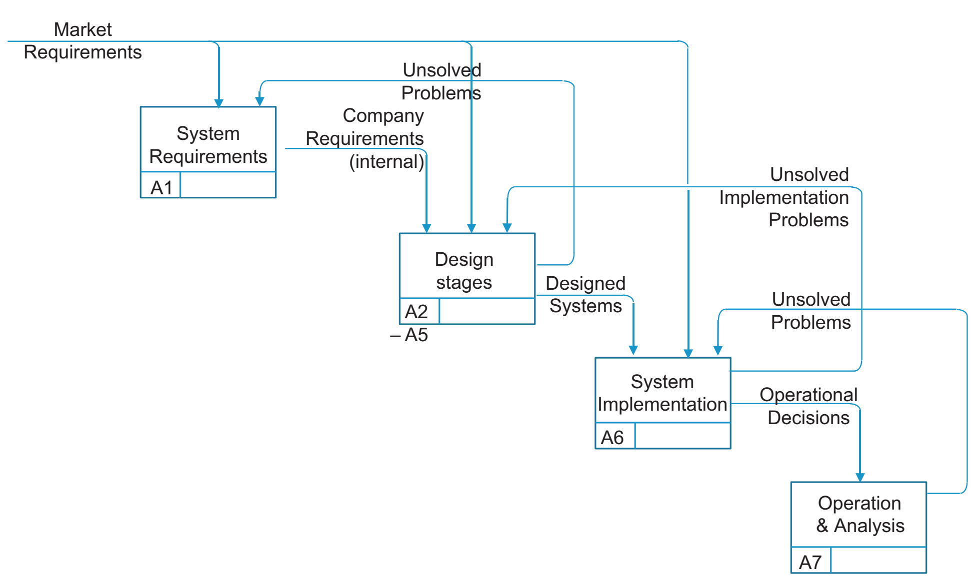


**Fig. 2.** A structured representation of a concurrent enterprise.