EVALUATING THE EFFECT OF HARVESTERS ON SUSTAINABILITY — A DESIGN STUDY

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Conventionally technology responds, through design, to a pre-defined set of requirements or functionalities to be effectively integrated in a product/devise. The functionality is usually in response to an extended ability, efficiency and/or convenience sought by the user (society) to enhance the productivity and convenience. Technology and design co-evolve, altering the living environment (and the society within) to accommodate this progression. It is the nature of this progression that determines sustainability in the context of a technology. The current paper evaluates sustainability in the context of harvesters, particularly focusing on its adoption in the Indian context.

Sustainability essentially implies maintaining a healthy living environment to indefinitely accommodate pursuits of society and development. Understanding and forecasting sustainability, in the context of a technology, could reveal likely enviro-socio-economic transitions and aid in the design of appropriate technologies. The current paper presents a comprehensive sustainability evaluation of harvesters, including a morphological design analysis and systems thinking based cross-impact analysis for forecasting. The adopted methodology envisages back-tracking sustainability trends to appreciate the linkages between technology design and sustainability. In addition, designers in particular would benefit from being able to perceive the larger picture of sustainability in the context of design.

Keywords: Technology, Design, Sustainability forecasting, Morphology, Systems thinking, Cross-impact analysis.

1. SUSTAINABILITY: TRADITIONAL VS MECHANISED AGRICULTURAL SYSTEMS

Demand for food grains acutely increased in the 1960's with a steep increase in population. The immediate need was to categorically increase crop yield/productivity within available land resources. Hitherto traditional agricultural systems/practices following natural cycles of (soil) nutrient replenishment and yield, that were self-sustaining, were evidently inadequate. This necessitated *technological* interventions *designed* to synthetically supplementing soil nutrients, assuring year-round water supply, reducing yield loss attributed to weeds and pests, and ensuring maximum harvest with engineered seeds. Choice of farmers shifted from traditional choices of rice to short-duration high yielding hybrid crop varieties; diversity of seeds shrunk and mono cropping took roots. However, regions in Asia, still predominantly remained dependent on traditional cattle and human *power* for agriculture. Specialized human skills related to agriculture were retained through knowledge passed on from generation to generation. The role of cattle in the Indian context is deeply rooted in rural agrarian life-style, from providing raw power for agriculture, transport and drawing water to a source of milk, energy and manure (dung). The transition to mechanization is particularly evident in the past decade, with machines getting more specialized in effectively performing multiple operations (concurrently replacing both human

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effort and skill and cattle power). While the immediate impact of mechanization was impressive, it consequently caused a systemic realignment to be increasingly efficient. Progressions in the man-nature complex attributed to this systemic realignment would determine sustainability and requires studied foresight.

The concept of sustainable development was brought to popular global attention at the World Commission on Environment and Development in 1984. Human beings are the centre of concern for sustainable development [1]) and this implies that livelihood and security determined by the state of the living environment, society and economy is ensured and sustained. The sustainable component of the sustainability paradigm fundamentally implies that current actions do not harm the ability of the future generations [2]. Sustainability in a system implies an ability of all to live a safe, healthy and productive life in harmony with nature.

1.1. Objectives of the study

The objective of the current study involves a methodological approach to evaluate and forecast sustainability in harvesters as a technology, attributed to its design, and enabling traceability of sustainability trends to design. It is necessary to discern the design in harvester technology to establish their influence on sustainability, well beyond immediate engineering-design concerns. This would provide an opportunity to investigate the implication of design (in technology) on its role in supporting a safe, healthy and productive society in harmony with nature. It is thus crucial to evolve and test an approach to discern the likely implications of a product's (harvester) adoption within the enviro-socio-economic system.

A typical scenario in a traditional agriculture system in south-India is taken as a basis for this study on the role of harvesters. Harvesting is one of the many closed-loop agricultural activities and the current study evaluates sustainability in the context of mechanization of this activity. The study also includes a comprehensive design-centric morphological evaluation of the harvester technology.

2. SUSTAINABILITY EVALUATION AND FORECASTING

In India, the agricultural system is deeply interconnected with natural (resource and climatic) cycles, socio-cultural practices and the local economy. Hitherto these systems have been economically self-sustaining and environmentally conducive. However, with the increasing influx of harvesters, the consequent implications on sustainability are not clearly evident. It is crucial to mention that discerning and maintaining sustainability at the local level is intrinsically linked with sustainability at the global scale [3].

Sustainability evaluation needs to consider two basic requirements — long range perception and systems thinking. To evaluate and forecast sustainability in harvesters, understanding the enviro-socio-economic dynamics of harvester use is paramount and would require a systems-thinking approach. The enviro-socio-economic triad has thus far remained the basis for sustainability evaluation. A systems approach to sustainability entails considering the various agents or entities interacting in the world as systems, which contains complex subsystems such as ecological and biological systems, weather systems, and human social and economic systems. Sustainability is characterized by the dynamic equilibrium among the variables characterizing entities within the system and the absence of run-away conditions depicting a lack of control. This involves evaluating and forecasting local and global sustainability trends within the system and analyzing the direction of the trends. Sustainability trends are characterized by the appropriate identification of indicators that are representative of the state of health in the system. Data about the entities within the system and those interacting with the system and the variables are crucial for robust inferences. A cross-impact analysis based systems approach has been adopted to capture (entity) variable interactions and generate the trends using a computer-based simulation model. Besides, the design of harvester technology requires careful investigation as it has a direct bearing on how the technology fits in and affects enviro-socio-economic dynamics.

2.1. Traditional agricultural practices in perspective

Harvesting essentially represents the process of gathering grains from mature crop. The process includes cutting the crop, threshing, winnowing, cleaning and storage and engaged the efforts of both man and animal. As indicated earlier, traditionally this activity was a social event engaging the entire community (men, women and children) and timed with the availability of migratory skilled workforce and marked with a harvest festival, which included paying respects to the land and cattle and offering the new grains to the local deity. This was followed with an occasion of distributing the harvest to the workforce, villagers and storage of the surplus. Agriculture was thus aiding social integrity and harmony. Traditionally animal and human efforts were taken for granted mainly due to availability of the same. Despite the low productivity and perceived drudgery the agro-economic subsystems sustained themselves comfortably till the food crisis in the 1960's posed a challenge to increase production and in turn the productivity. A systemic stability prevailed for centuries, wherein the cattle used were specialized for the demands of local agricultural burden with the choice in cropping pattern and seeds made in response to local demands of habitation, climatic-response, soil conditions and water availability [4]. To reiterate, the traditional system of paddy cultivation was a closed system (see Figure 1) with local interdependence among the humans, the animals and the ecosystem.

2.2. Role of Harvesters

Mechanization gradually but steadily replaced the animal and human powered methods to keep pace with the increased agricultural intensity. More than 80% of the agricultural activities in India employ some form of mechanization [5]. Mechanized harvesters are effective in vast plain lands with mono-cropping pattern. Irrigation and use of hybrid varieties of rice that are short in height and maturity duration have pushed up the grain productivity. In addition, government policies aimed at ensuring food security promoted the use of machines in agriculture at all levels with the provision of incentives. The harvester (technology) typically replaces animals and humans in performing paddy cutting, threshing and winnowing with marked improvement in efficiency. While the impact of complete mechanization of harvesting is yet to unfold, preliminary trends are already visible. The role of animals in paddy cultivation has steadily dwindled to less than 10% of farm efforts [5]. Figure 2 illustrates the transformation from the traditional close-looped agricultural system (see Figure 1) with the introduction of harvesters.

With farmers largely dependent on government-subsidized synthetic fertilizers loss of land fertility is now a global concern. Table 1 summarizes the traditional harvesting operations and the nature of associated efforts and their substitution with mechanization.

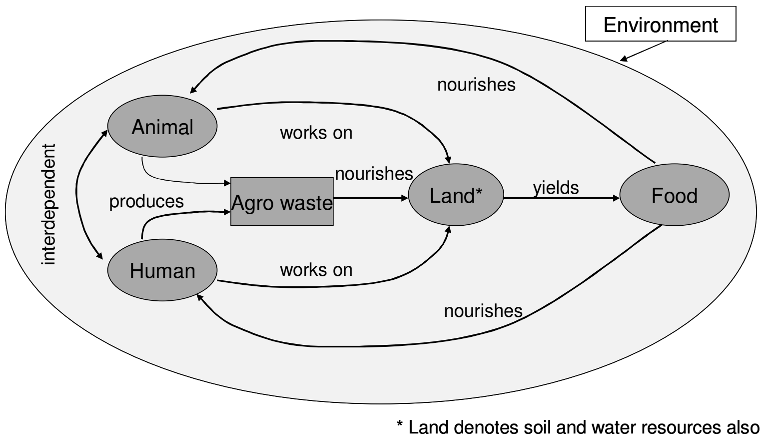


Figure 1. Traditional closed-loop agriculture system.

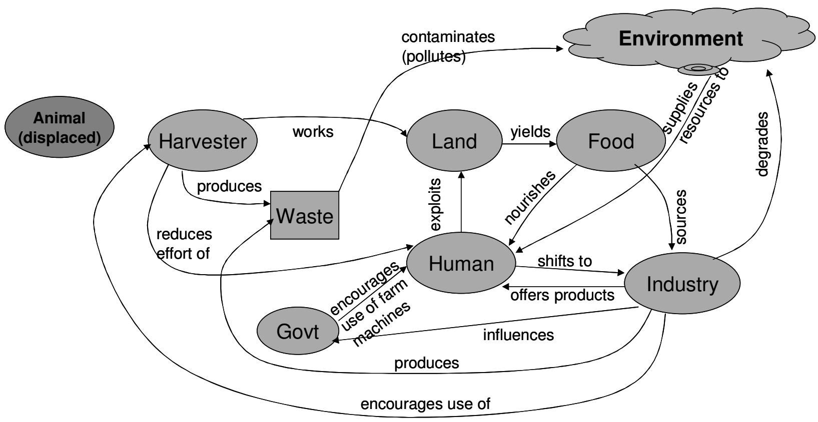


Figure 2. Altered interactions with the advent of mechanization in agriculture.

Table 1. Overview of Traditional Agriculture and the influence of mechanization.

Operation	What is it?	Efforts by	Effort	Extent of mechanization
Soil preparation	Plowing and leveling of the soil before sowing seeds	Human	Medium	Full
		Animal	High	
Fertilizing	Even distribution of manure or fertilizer over the cultivated area both before and after sowing	Human	Low	Partial
Sowing seed	Done in a nursery or directly in the field ensuring adequate distribution of seeds	Human + animal	Medium	Partial
Transplanting	Replanting the saplings from the nursery to the main field	Human	High	Nil
Irrigation	Providing necessary water for crop growth	Nature + Human	Climatic Medium	Partial
De-weeding	Physical removal of the weeds before they deplete the nutrients	Human	High	Partial
Paddy cutting	Paddy is cut leaving a short stem behind (composting)	Human	High	Full
Threshing	Separating grains from straw	Human and/or Animals	Medium	Full
Winnowing	Separation of chaff and straw from the grains	Human/natural breeze	Medium	Full
Cleaning	Separation of good grains from chaff and impurities	Human	Medium	Full
Storage	Cleaned grains are stored in sacks or granary pots	Human	Medium	Partial

3. SUSTAINABILITY IN HARVESTERS: THE ROLE OF DESIGN

A technology is generally designed to perform tasks of repetitive nature, and its satisfactory performance (time and effort) depends on both the technology and the environment being worked-on by technology. The design-structure of a technology determines its functional capability and thus its *behavior* within the human system. This would be particularly pertinent when back-tracking the implications of certain systemic traits to the design in technology. In the context of this paper a technology has been viewed as an *assembly* with the constituent (integrated) components, their geometric characteristics, material and process configuration being considered as elements of design. Keeping this view, a morphology analysis has been devised and adopted in this paper to delineate harvester technology in terms of its design elements.

3.1. Harvester Morphology

Morphology, by definition, is the study of the form and structure of organisms without considering associated functions. In the context of engineering design, a morphological chart helps capture the complete range of design alternatives/solutions for a product. It potentially broadens the scope for new solutions. Morphological Analysis is a systematic study to analyze the possible shape and form [6]. Morphological analysis is commonly used by designers to increase creative options for new design concepts before constraints are applied to narrow down the options for further stages of design [7].

The current study considers a variation of the conventional morphological analysis by structuring the technology by attributing options to various product features (design) serving a functionality/capability. For a generic multi-function harvester, this exercise provides insight into the available structure, function and design options, to subsequently trace their influence on sustainability. From a design perspective, the machine designs are adapted from the concepts in the industrialized nations. The design further evolved catering to local societal needs while concurrently leveraging on the technological advances. An indicative morphology of a generic harvester is shown in Table 2.

3.2. Sustainability Assessment and Forecasting: Methodology

Harvesters offer significantly enhanced efficiencies with the added advantage of in-situ operations. Many factors determine the suitability of harvesters for adoption in rural India. Besides, the terrain and the socio-economic factors also have a bearing on the adoption of mechanized harvesting. For the purpose of this study the term sustainability is interpreted as the ability to balance the benefits of mechanization with environmental and societal equilibrium, viz.

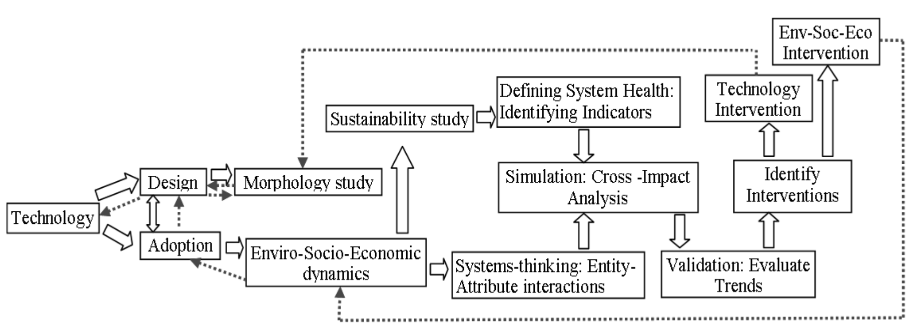
- Favourable trends
  - Agricultural productivity improvement (food security)
  - Increase in per capita income (employment and livelihood security)
- Detrimental effects (run-away trends)
  - Irrecoverable depletion of natural resources (land use, water)
  - Degradation of environment (contamination and fertility loss - soil, water, air)
  - Social disruptions (unemployment, social disharmony, migration)

The scheme proposed (See Figure 3) in this paper combines morphological analysis and Cross-Impact Matrix to explore the potential ramifications of non-engineering aspects of design, namely environmental and social impact.

In order to establish the effects of the harvester on sustainability a systems-thinking approach has been adopted to delineate the study system into sub-systems, entities, and their attributes. Entities perform activities resulting in impacts or systemic alterations characterized by change in system (entity) attributes. Systems-thinking concepts including linkages and feedback loops enable comparison to

Table 2. Morphology of a generic Harvester.

Dimension	Functional Characteristics	Options			
Body	Main enclosure	Metal	Fibre-reinforced plastic	Metal and plastic	
	Operator enclosure				
Power source	Type of engine	No engine	IC Engine		
	Type of fuel	Diesel	Petrol	Kerosene	Gas
	Autonomy	Manual	Self propelled	Assisted by external motor	
Operation mode	Terrain	Flat	Gradient	Steps	
	Compatibility to land type	Loose soil	Clay	Marsh	Hard soil
	Weather compatibility	Sunny	Rainy	Dusty	
	Safety features	Speed limiter	Collision detector	Shielded blade	Safety grill
	Maintenance	User serviceable	Proprietary skills needed	Road-side mechanic can	
Performance	Harvest rate	0.5 ha/day	1 ha/day	>1 ha/day	
	Fuel consumption	1 litres/ha	2 litres/ha	>2 litres/ha	
	Cutting height	Low	Medium	High	
Mobility	Tyre specification	Rubber + tube/tubeless		Solid rubber	Steel
	Gears	Forward	Reverse	Load	
Size	Overall length	<4m	>10M		
	Weight	<500Kg	0. −1.0 ton	> 1 ton	
	Width of the cutter	<2 m	2−5 m	>5 m	
Fixtures	Height of the cutter	Adjustable	Fixed		
	Cutting unit	Variable width	Fixed width	Height adjustable	
	Blade	Steel	Alloys	Hardened steel	
	Replaceable				
	Serviceable				
	Threshing unit	Drum	Impact		
	Winnowing/blower unit	Variable blower speed	Synchronized to cuttingspeed		
	Grain dispenser	Sack filler	Streaming	In-built container	Collector
truck	Chaff dispenser	Air blow	Gravity	Collected	Dispersed



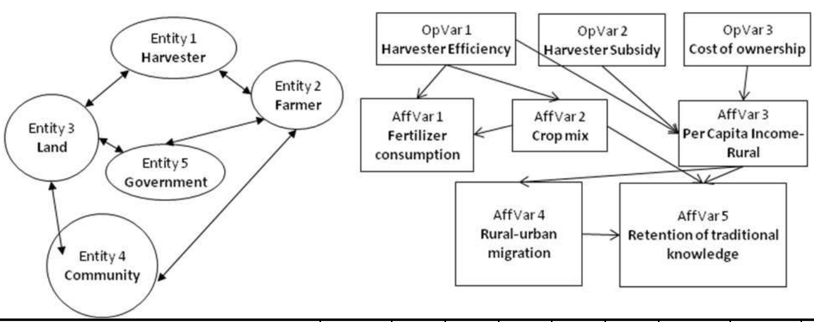
Legend: Block arrow: Process direction Dotted line: Feedback path

Figure 3. Schematic of the methodology.

reference scenarios and analysis of alternative scenarios by tracing causes of change [8]. Seemingly insignificant and small occurrences (man-made or natural) can produce unpredictable and drastic results triggering a series of increasingly significant events [9]. For a more methodical capture of systems dynamics a cross-impact analysis technique termed Kane's Simulation (KSIM) [10, 11] has been adopted in this paper. KSIM also permits short and long-term forecasting based on system dynamics captured as pair-wise attribute interactions. The simplicity of KSIM lies in its feature that qualitative inputs for interactions are valid inputs. Mani *et al*. [3] provides an elaborate illustration on the adoption of this technique. A probabilistic approach can be found in [12].

Besides, this paper proposes to categorize the attributes into two groups; the **Option variables** and the **Affected variables**. Option variables are the attributes derived from the product morphology (see Table 2) that captures various options for certain features/functionality of the harvester. The Affected variables are the handles to gauge the impact on the entities of concern, which may or may not be explicit in the product requirements or the engineering specifications. The terms attribute and variable are used synonymously. This set of variables essentially allows the designer to generate configurations of the harvester while allowing a sustainability appraisal via the Cross-Impact Matrix as shown in Figure 4.

In the context of this study, the focus of sustainability evaluation would lie on the affected variables as their trends are significant in establishing relevant influences on the harvester and its design. The likely nature of influences of the column (impacting) variable on the row (impacted) variable is depicted in the Cross-Impact Matrix either as increasing or decreasing arrows. The strength of the influence is denoted by the number of arrows. These arrows are later substituted with statistical data and/or elicited from experts familiar with the system.



Affected variables	Rural-urban migration	Crop variety (mix)	Draught animal power	Per capita income – Rural	Retention of traditional knowledge	Subsidy for farm mechanization	Cost of ownership of harvesters	Harvester rate (ha/hr)	Harvester size	Fertilizer consumption per unit area
Rural-urban migration	↑↑						↓			
Crop variety (mix)									↓	↓
Draught animal power					↑	↓	↑↑	↑↑		
Per capita income – Rural	↓						↓	↑		
Retention of traditional knowledge	↓↓	↓								
Fossil fuel consumption (per unit area)						↑	↓	↑	↑	
Fertilizer consumption per unit area			↓		↓		↑		↑	

Cross-Impact Matrix (impact of column variable on the row variable)

Figure 4. Entity structure, Attribute interactions and the Cross-impact matrix.

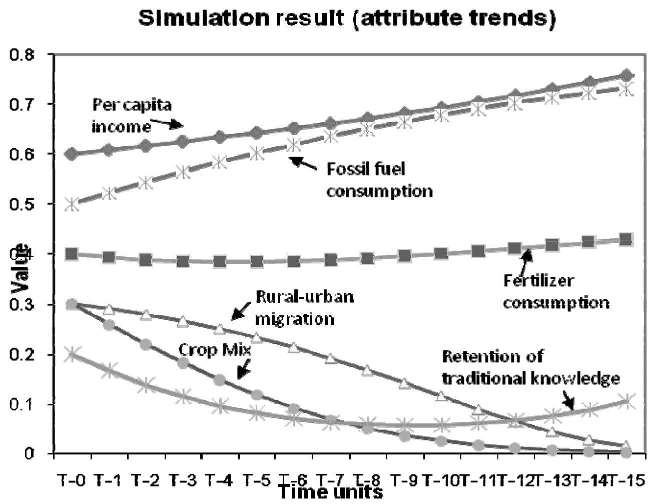


Figure 5. Attribute trends from KSIM using Cross-Impact Matrix.

4. RESULTS

The following section presents results and conclusions based on the sustainability evaluation and forecasting study on the role of harvesters using the KSIM. Given the fact that data availability for all the systems variables were scattered and scarce, the simulation relied on a group of experts to determine the attributes and their interactions. Figure 5 illustrates the system forecast for select variables pertinent to evaluating sustainability. In addition, these variables can also be traced back to the specific design feature of the harvester technology using the entity-attribute linkages.

Salient sustainability trends are as follows:

The favourable trends seen in the simulation output are (a) improvement in rural per capita income (attributable to harvester efficiency and lower costs) and (b) rural-urban migration (attributable to harvester efficiency and subsidy). The trends of increasing fossil fuel consumption, mono-cropping (attributable to harvester cutter design) and erosion of traditional agricultural knowledge suggest that the harvester is likely to degrade the environment in the long, despite positive economic benefits. By tracing back to the design (option) variables it is possible to identify the range of values, or the design (subset) choices to address in the technology. This is made possible by investigating the harvester morphology.

5. CONCLUSIONS

The current paper discusses and presents results following a sustainability evaluation of harvesters, including a morphological design analysis and systems thinking based cross-impact analysis for forecasting. The adopted methodology envisages back-tracking sustainability trends to appreciate the linkages between technology design and sustainability. Designers in particular would benefit from being able to perceive the larger picture of sustainability in the context of design. The idea of Design (option) variables and Affected variables helps the designer to explore the likely non-engineering consequences of the product during the design phase itself. The proposed use of simulation to forecast likely trends and the ability to trace back to (technology) design would permit the selection of design options to create desirable sustainability influences. Using inferences from such forecasts product design can be augmented with additional insights over and above meeting conventional requirements of intended functionality. Validation in real-world applications is necessary to understand the data requirements for reliable projections and design linkages to evaluate various design options for their impact on sustainability.

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