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Design and Development of an Effective Sensing and Measurement Procedure for Tasks for System-of-Systems Engineering Management in the Agro-Seed Nurturing Industry †

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Abstract: This research has quantified, through algorithmic sensing and metrication, the minimum management effort required by a System-of-Systems (SoS) overseeing entity to competitively manage the complex network of systems that form a heterogenous SoS cluster. In a bid to achieve this, a holistic and integrated framework depicting a SoS network of 35 constituent systems in the agricultural grain industry was developed. Furthermore, a quantitative mechanism via the Hybrid Structural Interaction Matrix (HSIM) concept was deployed. From this, it was realized that the effective minimum management score required for the attainment of competitiveness in holistic management herein is 0.534067.

Keywords: systems-of-systems engineering management; sensing of management effort; agro-seed nurturing industry; measurement of management effort; measurement of competitiveness; hybrid structure interaction matrix; heterogenous systems of systems

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1. Introduction

The management of complex systems, irrespective of the human corporate entity they belong to, spanning across sectors such as manufacturing, agriculture, education, transportation and a host of others [1], requires an effective, structured, yet simplified approach [2,3]. While an effort is made to fill the research gaps in the complex System-of-Systems (SoS) field, there is no set framework for the management of SoSs [2–5]. Creating such a framework can be a daunting task without any form of procedural sensing and measurement strategies or benchmarks aimed at quantifying the management effort required across the chain of tasks and activities of the systemic entities [6]. In the above light, the concept of SoS management for effectiveness and competitiveness is presented in an effort to categorize the nature of the complex system being addressed in this research. SoSs often consist of multiple operational, managerial, and geographically independent systems that collaborate in order to create a new integrated network capable of fulfilling a purpose that cannot be achieved by any one individual constituent system in the network [7,8]. Due to the independent nature of the constituent systems, the holistic management of the SoS impacts the overall competitiveness and risk management thereof [9,10]. The measurement of competitiveness of SoSs, achieved through task and activity perception and metrification, results in the management effort of the interrelated constituent systems, also referred to as System-of-Systems Engineering Management (SoSEM).

In a bid to quantify the competitiveness, a metric system was developed and deployed to identify, sense, and measure the management effort in an SoS environment, where multiple diverse constituent systems interact. Grain South Africa (GSA) serves as the centric system that conducts oversight in the agro-seed processing industry SoSs. Thus, GSA requires effective and competitive management of the conglomeration of external heterogenous constituent systems in the SoSs.

In this research, the competitiveness was determined by means of the following objectives:

- Architecting a holistic framework that depicts the heterogeneous SoSs in the agro-seed nurturing (grain) industry, with GSA as the centric system;
- Developing a metric system via the Hybrid Structure Interaction Matrix (HSIM) comparative model approach for the identification, sensing and measurement of the overall quantitative evaluation of the SoSEM towards industry competitiveness.

The HSIM-comparative approach is premised on the theory of subordination and makes use of a binary weight assignment scheme which, over time, translates into a continuous weight assignment mechanism [11–13].

2. Research Methodology

The research methodology is divided into two parts, namely, the architecture of the SoS network and the development of the metric system. Both were applied in the context of a case study in the agro-seed nurturing industry.

2.1. Architecture of the SoS Network

The SoS network originates from a System-of-Subsystems (SoSub) network. The steps involved in architecting the network include:

1. Define the centric system and develop its subsystems according to the systems structure architecture, as depicted in Figure 1;
2. Define all external entities interacting with the centric system;
3. Develop the subsystems for each external entity, according to the systems structure architecture, similar to Step 1;
4. Determine the interrelationships between the entities (centric and external) by defining the interrelationships between the external entity subsystems relating to the subsystems of the centric entity;
5. Draw an SoS network showing the systems and their interrelationships.

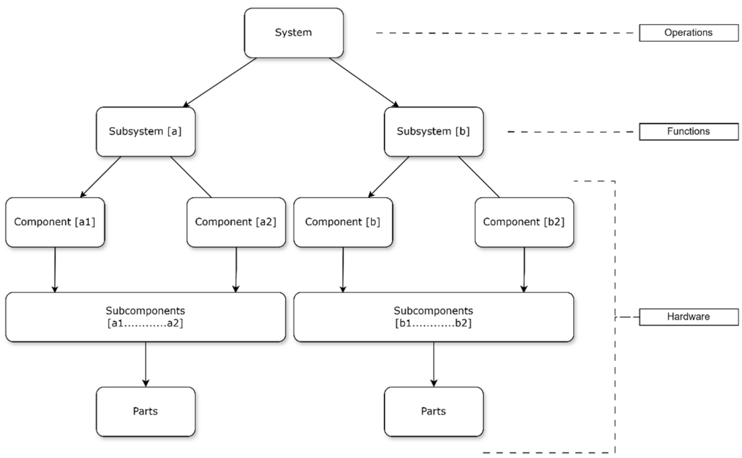

Figure 1. Architecting template for the structure of a system [14].

2.2. Development of Metric System

The HSIM comparative model makes use of a time-variant approach to offer a method for investigating management effort required to maintain SoS competitiveness. Weight assignment was used to do numerical analyses of the systems in the SoS network. The hierarchical organization of systems is premised on the theory of subordination, but unlike the conventional HSIM concept, a SoS network diagram was used rather than a hierarchical tree-structured diagram (HTSD).

From the SoS network diagram, some constituent systems were identified, prioritized, and ranked in order of significance using the principle of subordination. The actual normalized weight of each constituent system was then determined based on the estimated normalized weight of each constituent system. Ultimately, an effective minimum management score required for competitiveness attainment was generated. By directing more managerial effort to the most weighted constituent system, the HSIM concept applied in the grain case study attempts to provide a method for dealing with the measurement of competitiveness.

For the application of the HSIM concept, the focus is on the interactions between constituent systems. A given systems pair can interact in a variety of ways, in accordance with the HSIM principle. Using the Binary Interaction Matrix (BIM) concept of the HSIM method, the systems' interactions based on a specific contextual relationship were used to construct an inter-systems pairwise matrix.

For the case study, the focus was on the virtual and physical interactions between the constituent systems. Virtual interactions include the propagation of information or data flow, whereas physical interactions include the effort required to manage the hardware and people of constituent systems. For each interaction mentioned, a contextual question (CQ) was developed from which the inter-systems pairwise matrix was determined. This was done by allocating either the number 0 or 1 to the interaction between system i and system j, such that:

$$S_{ij} = \begin{cases} 0,\ \textit{no interaction, i.e., answer to CQ is ``no''} \\ 1,\ \textit{unidirectional interaction, i.e., answer to CQ is ``yes''} \\ S_{ji} = 1,\ \textit{bidirectional interaction, i.e., answer to CQ is}\ \text{neutral/equal}, \end{cases}$$

where S_{ij} denotes the constituent systems of row i and column j. As can be seen in the third instance, S_{ij} and S_{ji} can both be "1" since the deployment of the HSIM approach herein is not about prioritization but the sharing of resources between any two constituent systems.

The step-by-step procedure for establishing the HSIM for a given conglomeration of heterogeneous constituent systems is depicted in Figure 2.

The model for calculating weight assignment is as follows:

$$I_{RFi} = \left(\frac{N_{SFi}}{T_{NF}}.M_{SR}\right) + \left(\frac{b}{T_{NF}}\right)(M_{SR} - C),$$

$$C = \frac{M_{PSF}\ .\ M_{SR}}{T_{NF}},$$

$$B = N_{SFi} + 1,$$

where I_{RFi} is the intensity of system i's significance rating, N_{SFi} is the number of subordinate systems to a particular system i, M_{PSF} is the maximum number of subordinate systems that can be considered, C is constant, B is the proportion of variations, T_{NF} is the number of systems in total, and M_{SR} is the maximum possible scale rating.

Additionally, the following technique was used to normalize the ratings:

1. For each constituent system identified in the case study, organize the I_{RFi}-ratings per matrix into a column matrix, as can be seen in Table 1;
2. Determine the overall I_{RFi}-rating by averaging the I_{RFi} -rating of the virtual interaction matrices and the I_{RFi} -rating physical interaction matrices and add to the column matrix from Step 1;
3. Calculate each rating's nth root, where n denotes the total number of constituent systems considered;
4. Add Step 3's findings together and calculate the sum total;
5. Divide Step 3's nth root for each constituent system by Step 4's summation.

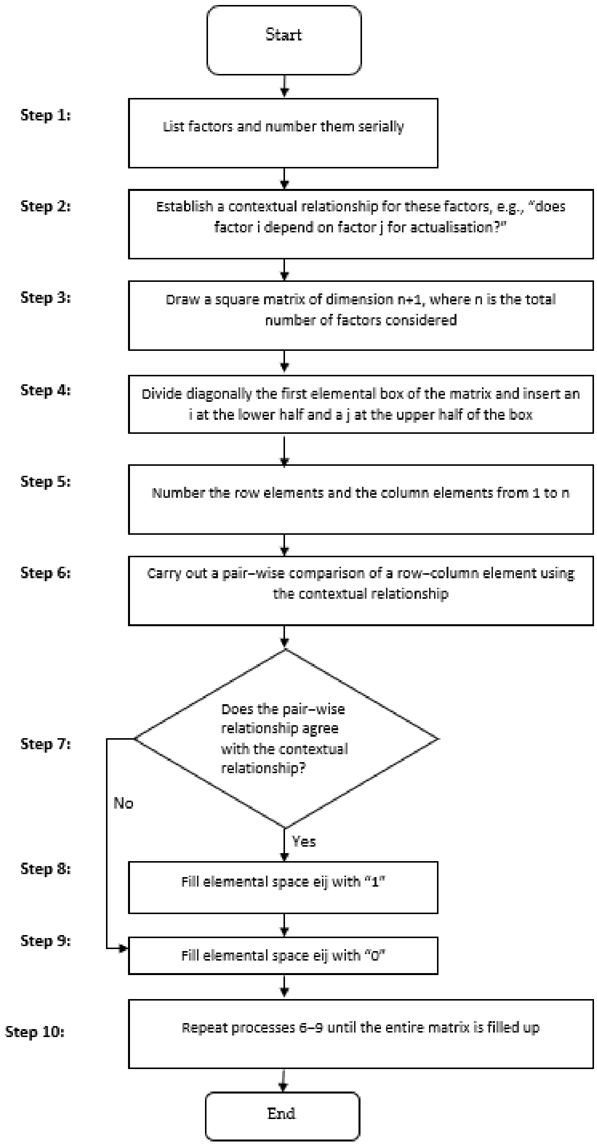

Figure 2. Diagram of the HSIM development process [11].

The three stages are combined to create the following model:

$$N_{Wi} = \frac{(x_i)^{1/n}}{\sum_{i=1}^{n} (x_i)^{1/n}},$$

where N_{Wi} is the system's normalized weight i, n is the number of systems, and x_i is the original rate of system i before normalization.

The following is a generalized version of the steps for determining the effective minimum management score required for competitiveness attainment:

1. Sort normalized scores into a sequenced ascending order, e.g., {0 to 1} for n system entities;
2. Obtain the average of the scores;
3. Separate normalized scores into two clusters viz.:
   a. below-average scores should be in one cluster,
   b. equal-to- or above-average scores should form another cluster;
4. Count how many scores are in each cluster;
5. Determine what percentage of the total number of scores is the number per cluster;
6. Multiply the outcome of Step 5 by the sum of scores per cluster;

7. Sum the outcomes in Step 6 to determine the effective minimum management score required for competitiveness attainment.

3. Case Study: Grain South Africa

The agro-seed processing industry, where grains are nurtured and developed, is largely non-objective due to the chain of embedded and interconnected non-metric qualitative tasks and activities. Therefore, traditionally, the procedures available for the identification, sensing, and measurement of competitiveness of SoSs are often limited to verbal articulations, physical observations, and benchmarking of tasks with desired task targets, amongst others.

In South Africa, the agricultural sector is one of the biggest contributors to the country's gross domestic product (GDP) [15]. Subsequently, the biggest contributor to agriculture is field crops (39%), of which the biggest contributing crop is grain (30%), comprising larger commercial and smaller subsistence farms [16]. Despite its importance, the agro-seed processing (grain) industry earnings remain low compared to its potential contribution [17]. Therefore, the need to improve competitiveness in the management of this sector is evident.

In this case study, GSA serves as the centric system that conducts oversight in the agro-seed processing industry. GSA is an autonomous and voluntary industry organization that acts collectively in the economic interest of the South African grain producers [16]. In this case study, GSA is denoted as System 15 (S15), as seen in Table 1. The external, standalone constituent systems deployed in this research for the SoS managerial studies are presented from one to thirty-five in Table 1.

Table 1. Constituent systems of the agro-seed processing industry SoSs.

Si	System Name		Description
S1	SACTA	South African Cultivar and Technology Agency	Research Responsible for ongoing innovation in plant breeding and technology development of crop cultivars [18].
S2	SAGL	Southern African Grain Laboratory	Research A reference laboratory for grain and oilseeds, which delivers market-driven analytical laboratory services for grains, including maize, wheat, sorghum, sunflower, and soybeans [19].
S3	PRF	Protein Research Foundation	Research Responsible for researching better protein utilization and technology transfers to replace imported protein for animal use with locally produced protein [20].
S4	ARC	Agricultural Research Council	Research Reports to DALRRD (S20) and is a science institution that fosters innovation to develop the agricultural sector by means of several research campuses, which are predominantly commodity-based [21].
S5	Fertasa	Fertilizer Association of Southern Africa	Supply Chain Player (Input Provider) Represents the fertilizer industry and its members [22].
S6	SANSOR	South African National Seed Organization	Supply Chain Player (Input Provider) The National Designated Authority (NDA) to certify that seed was produced, inspected, and graded according to the legislated standards and systems [23].
S7	SAAMA	South African Agricultural Machinery Association	Supply Chain Player (Input Provider) The official body representing the interest of agricultural machinery manufacturers, importers, and builders [24].
S8	NCM	National Chamber of Milling	Supply Chain Player (Processor) A non-profit trade organization representing the interest of the South African flour and maize milling industry [25].

Table 1. *Cont.*

Si		System Name	Description
S9	SACB	South African Chamber of Baking	Supply Chain Player (Processor) A non-profit trade organization representing the interest of the South African baking industry [26].
S10	AFMA	Animal Feed Manufacturers Association of South Africa	Supply Chain Player (Processor) A non-profit trade organization representing the interest of the South African animal feed industry [27].
S11	Agbiz Grain	Grain Silo Industry Agribusinesses	Supply Chain Player (Storage) A non-profit trade organization representing the interest of the South African grain storage and handling industry [28].
S12	SACOTA	South African Cereals and Oilseeds Traders Association	Supply Chain Player (Trader) Represents the interest of the South African grain traders' industry [29].
S13	PPECB	Perishable Products Export Control Board	Supply Chain Player (Trader) Mandated by DALRRD (S20) and reports to dtic (S21). It is South Africa's official independent certification agency, delivering end-point inspection services on perishable products destined for export [30].
S14	ITAC	International Trade Administration Commission of South Africa	Supply Chain Player (Trader) Reports to dtic (S21) and is responsible for the administration around international trade to foster economic growth and development in South Africa [31].
S15	GSA	Grain South Africa	-
S16	BFAP	Bureau for Food and Agricultural Policy	Economy/Market Information A non-profit organization responsible for providing unbiased, research-based market and policy insights to inform decision-making by stakeholders in the agricultural, agro-processing, and food sectors across Africa [15].
S17	SAGIS	South African Grain Information Service	Economy/Market Information A non-profit company responsible for providing the grain industry with essential market information by verifying submitted data from co-workers [32].
S18	NAMC	National Agricultural Marketing Council	Economy/Market Information Reports to DALRRD (S20) and is responsible for providing marketing advisory services to key stakeholders in support of a vibrant agricultural marketing system in South Africa [33].
S19	CEC/CELC	Crop Estimates (Liaison) Committee	Economy/Market Information An independent committee providing accurate, timely, and credible crop estimates to stakeholders in the grain industry [34].
S20	DALRRD	Department of Agriculture, Land Reform, and Rural Development	Government A government department with reporting entities including ARC (S4), NAMC (S18), and PPECB (S13) [35].
S21	dtic	Department of Trade, Industry, and Competition	Government A government department with reporting entities including ITAC (S14), NAMC (S18), and PPECB (S13) [36].
S22	TLU-SA/ TAU-SA	Transvaal Agricultural Union of South Africa	Interest Representative A farmer's union representing predominantly Afrikaans farmers [37].
S23	AFASA	African Farmers Association of South Africa	Interest Representative A farmer's union representing predominantly African farmers [38].
S24	Maize Trust	Maize Trust	Interest Representative Trust that provides funding for the benefit of the maize industry—in particular, for maize research and development projects and the maintenance of market information required by the industry [39].

Table 1. *Cont.*

Si	System Name		Description
S25	Sorghum Trust	Sorghum Trust	Interest Representative Trust that provides funding for the benefit of the sorghum industry—in particular, for sorghum research and development projects and the maintenance of market information required by the industry [40].
S26	SAWCIT	South African Winter Cereal Industry Trust	Interest Representative Trust that provides funding for the benefit of the winter cereal industry—in particular, for winter cereal research and development projects and the maintenance of market information required by the industry [41].
S27	OPOT/OPDT	Oil and Protein Seed Development Trust	Interest Representative Trust that provides funding for the benefit of the oilseeds industry—in particular, for oilseed research and development projects and the maintenance of market information required by the industry [42].
S28	AWSA	Agricultural Writers South Africa	Economy/Market Information A voluntary, non-profit professional association promoting the image and standards of agricultural journalism in South Africa through radio, magazines, newspapers, and television [43].
S29	AgriSA	Agriculture South Africa	Interest Representative A federation of agricultural organizations with member organizations representing different provincial agricultural unions, commodity organizations, and agribusinesses [44].
S30	CropLife	CropLife	Development A non-profit association that provides crop protection, public health, and plant biotechnology solutions in South Africa via research and training [45].
S31	AgriSETA	Agriculture Sector Education and Training Authority	Development Funded by the NT (S32) and provides learning programs and education, as well as conducts research in the agricultural sector [46].
S32	NT	National Treasury	Government A government department with reporting entities including LandBank (S33), SARS (S34), and Safex (S35) [47].
S33	LandBank	Land and Agricultural Development Bank of South Africa	Development A specialist agricultural development finance institution that provides financial services and products to the commercial farming sector and agri-businesses. Collaborate on the Blended Finance Scheme with DALRRD (S20) [48].
S34	SARS	South African Revenue Service	Economy/Market Information Responsible for the collection of all revenues due, ensuring optimal compliance with tax and customs legislation and providing a customs and excise service that will facilitate legitimate trade as well as protect the economy and society [49].
S35	JSE Safex	South African Futures Exchange	Economy/Market Information A futures exchange subsidiary of JSE Limited, the Johannesburg-based exchange provides a platform for price discovery and efficient price risk management for the grains market in South and Southern Africa [50].

4. Results and Discussion

This section summarizes the results obtained for the architecture of the SoS network and the development of the metric system.

4.1. System of Systems Network Architecture

Figure 3 depicts how the external entities connect to GSA (in red), as well as how they connect to each other (in black).

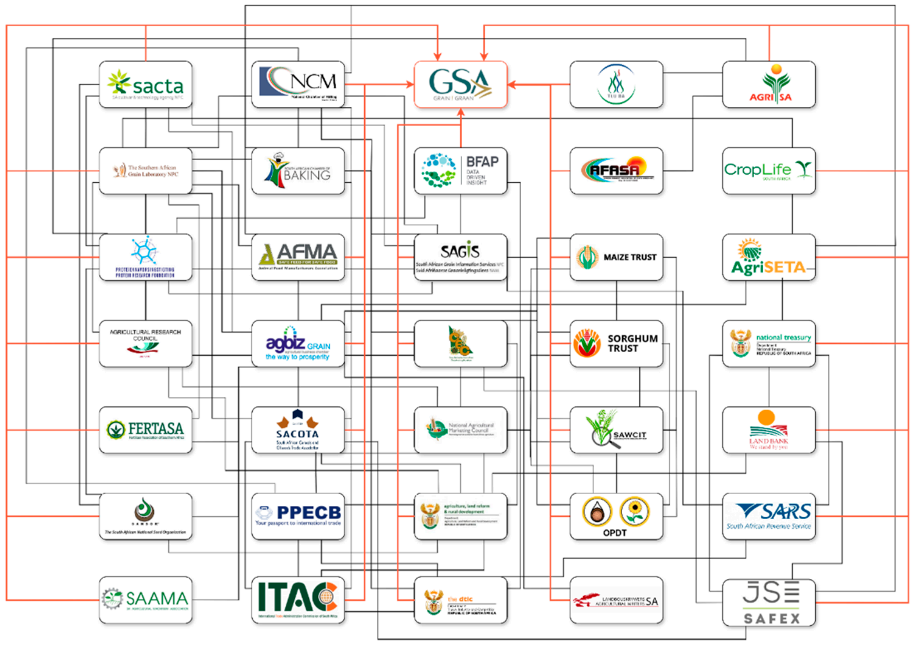

Figure 3. SoS network for GSA and external entities.

4.2. Metric System for System of Systems Network

From Figure 3, it is evident that the agro-seed nurturing (grain) industry is a complex system. To quantify the virtual and physical interactions between the systems (GSA and the external entities), the HSIM concept was applied.

4.2.1. Virtual Interaction: Information and Communication Matrix

The relevant CQ is "Does system *i* give or propagate information or communicate signals or data to system *j*?". Figure 4 depicts the HSIM (binary interaction matrix) for the above-mentioned CQ.

i \ j	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	
S1	0	1	1	1	0	1	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	11
S2	1	0	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0	16
S3	1	1	0	1	0	1	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	9
S4	1	1	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	1	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0	12
S5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S6	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
S7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S8	0	1	0	0	0	0	0	0	1	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	7
S9	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4
S10	0	1	1	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6
S11	0	1	0	1	1	0	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	1	1	1	1	1	1	0	0	1	0	0	0	14
S12	0	0	0	0	0	0	0	1	1	1	1	0	1	1	1	0	1	1	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	1	1	17
S13	0	0	0	1	0	0	0	1	0	1	0	1	0	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	10
S14	0	0	0	0	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	9
S15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	6
S16	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
S17	0	1	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	15
S18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	7
S19	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1	0	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	23
S20	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
S21	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	12
S22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2
S23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2
S24	1	1	0	1	0	0	0	1	0	1	1	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	11
S25	1	1	0	1	0	0	0	1	0	0	1	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	10
S26	1	1	0	1	0	0	0	1	0	1	1	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	11
S27	1	1	1	1	0	0	0	0	0	1	1	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	11
S28	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3
S29	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	4
S30	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2
S32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	5
S33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
S34	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6
S35	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	9 275
	9	14	8	12	4	5	4	11	8	13	16	9	6	5	32	2	17	10	2	12	4	1	1	9	9	9	9	3	8	1	4	7	1	4	6	
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Figure 4. Information HSIM demonstrating the pairwise connection between the systems.

For example, in Figure 4, $S_{ij} = S_{ji}$, where $S_{12} = S_{21}$. This is because there is bidirectional sharing of resources between System 1 and System 2, and SACTA and SAGL, respectively.

4.2.2. Physical Interaction: Hardware Matrix

The relevant CQ is "Does system *i* have in its custody more hardware to manage in terms of their numbers and critical nature in comparison to system *j*?". Figure 5 depicts the HSIM (binary interaction matrix) for the above-mentioned CQ.

i \ j	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35		
S1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	7	
S2	1	0	1	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	1	1	1	1	0	0	1	0	0	0	0	0	20	
S3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	5	
S4	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	0	0	28	
S5	1	1	1	1	0	1	1	1	1	1	0	0	0	0	1	0	1	0	1	0	0	0	0	1	1	1	1	0	0	1	0	0	0	0	0	17	
S6	1	1	1	1	1	0	1	1	1	1	0	0	0	0	1	0	1	0	1	0	0	0	0	1	1	1	1	0	0	1	0	0	0	0	0	17	
S7	1	0	1	1	1	1	0	1	1	1	0	0	0	0	1	0	1	0	1	0	0	0	0	1	1	1	1	0	0	1	0	0	0	0	0	16	
S8	1	0	1	0	1	1	1	0	1	1	1	0	0	0	1	0	1	0	1	0	0	0	0	1	1	1	1	0	0	1	0	0	0	0	0	16	
S9	1	0	1	0	1	1	1	1	0	1	1	0	0	0	1	0	1	0	1	0	0	0	0	1	1	1	1	0	0	1	0	0	0	0	0	16	
S10	1	0	1	0	1	1	1	1	1	0	1	0	0	0	1	0	1	0	1	0	0	0	0	1	1	1	1	0	0	1	0	0	0	0	0	16	
S11	1	1	1	1	1	1	1	1	1	1	0	1	0	0	1	0	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	0	1	0	0	24	
S12	1	0	1	0	1	1	1	1	1	1	1	0	0	0	1	0	1	1	1	0	0	0	0	1	1	1	1	1	0	1	0	0	0	0	0	19	
S13	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	0	1	0	0	25	
S14	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	0	0	27	
S15	1	1	1	0	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	0	1	0	0	23	
S16	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	0	1	1	1	0	0	1	1	1	1	1	1	0	1	0	1	0	1	0	0	24	
S17	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	0	1	0	0	0	0	0	8	
S18	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	0	0	27	
S19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	4	
S20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	34	
S21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	34	
S22	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	0	1	1	0	1	0	0	27	
S23	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	1	1	0	1	1	0	1	0	0	27	
S24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	4	
S25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	4	
S26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	4	
S27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	4	
S28	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0	0	0	24	
S29	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	1	1	0	1	0	0	29	
S30	1	0	1	0	0	0	0	1	1	1	0	0	0	0	0	1	1	0	1	0	0	0	0	1	1	1	1	0	0	0	0	0	1	0	0	13	
S31	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	0	1	0	0	29	
S32	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	34	
S33	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	29	
S34	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	0	0	30	
S35	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1	0	31	696
	27	18	29	14	25	25	25	25	25	25	22	19	15	13	25	15	28	18	34	2	2	14	14	34	34	34	34	18	14	26	17	2	17	4	3		
																																			696		

Figure 5. Hardware HSIM demonstrating the pairwise connection between the systems.

4.2.3. Physical Interaction: People Matrix

The relevant CQ is "Does system *i* have more human resource in its custody to manage in comparison with system *j*?". Figure 6 depicts the HSIM (binary interaction matrix) for the above-mentioned CQ.

4.3. HSIM Calculations

Table 2 shows the overall significance rating of the constituent systems, as derived from the matrices in Figures 4–6. In addition, the normalized values of the significance rating in ascending order are depicted in Table 3.

The model for calculating weight assignment, using S1 in the information matrix as an example, as seen in Table 2 in red:

$$I_{RFi} = \left(\frac{N_{SFi}}{T_{NF}}.M_{SR}\right) + \left(\frac{b}{T_{NF}}\right)(M_{SR} - C)$$

$$I_{RF1} = \left(\frac{11}{35}.9\right) + \left(\frac{12}{35}\right)(9 - 8.742857) = 2.916735$$

$$where\ C = \frac{34 * 9}{35} = 8.742857$$

$$and\ B = 11 + 1 = 12$$

The $I_{RF-overall}$ was calculated by averaging the ratings of the virtual and physical interaction matrices. For the physical interaction, $I_{RF-physical}$ = average of the $I_{RF-hardware}$ and $I_{RF-people}$. For the virtual interaction, $I_{RF-virtual}$ = $I_{RF-information}$.

Therefore, for the overall rating of S1 as an example, as seen in Table 2 in blue:

$$I_{RF1-overall} = \frac{I_{RF1-virtual} + \frac{I_{RF1-physical1} + I_{RF1-physical2}}{2}}{2}$$

$$I_{RF1-overall} = \frac{2.916735 + \frac{1.858776+3.974694}{2}}{2} = 2.916735$$

The following model was applied to normalize the weight, using S1 as an example, as seen in Table 3 in green:

$$N_{W1} = \frac{(x_i)^{1/n}}{\sum_{i=1}^{n}(x_i)^{1/n}}$$

$$N_{Wi} = \frac{(2.916735)^{1/35}}{\sum_{i=1}^{35}(2.916735)^{1/35}\ldots(5.429387)^{1/35}}$$

$$N_{W1} = \frac{(2.916735)^{1/35}}{26.233868} = 0.028456$$

The effective minimum management score required for competitiveness attainment was calculated, as seen in Table 3 in yellow.

The top five most rated systems are S35. S4. S34. S14. and S2 (highest to lowest). as can be seen in Table 2. These systems are Safex,. ARC. SARS, ITAC. and SAGL. respectively. Therefore. more managerial effort must be directed to these most weighted constituent systems to improve the overall measure of competitiveness of the grain SoSs.

Table 2. Significance rating of constituent systems.

	Significance Rating			
	Virtual Interactions	**Physical Interactions**		**Overall**
	Information Matrix	**Hardware Matrix**	**People Matrix**	
S1	2.916735	1.858776	3.974694	2.916735
S2	4.239184	5.297143	5.826122	4.900408
S3	2.387755	1.329796	0.800816	1.726531
S4	3.181224	7.413061	7.677551	5.363265
S5	0.536327	4.503673	7.148571	3.181224
S6	1.329796	4.503673	3.445714	2.652245
S7	0.271837	4.239184	4.768163	2.387755
S8	1.858776	4.239184	5.826122	3.445714
S9	1.065306	4.239184	2.123265	2.123265
S10	1.594286	4.239184	6.619592	3.511837
S11	3.710204	6.355102	3.974694	4.437551
S12	4.503673	5.032653	1.594286	3.908571
S13	2.652245	6.619592	3.445714	3.842449
S14	2.387755	7.148571	8.206531	5.032653
S15	1.594286	6.090612	8.206531	4.371429
S16	1.065306	6.355102	4.768163	3.313469
S17	3.974694	2.123265	5.297143	3.842449
S18	1.858776	7.148571	6.884082	4.437551
S19	6.090612	1.065306	1.594286	3.710204

Table 2. *Cont.*

	Significance Rating			
	Virtual Interactions	Physical Interactions		Overall
	Information Matrix	Hardware Matrix	People Matrix	
S20	1.065306	9.000000	2.916735	3.511837
S21	3.181224	9.000000	2.916735	4.569796
S22	0.536327	7.148571	6.619592	3.710204
S23	0.536327	7.148571	6.619592	3.710204
S24	2.916735	1.065306	1.594286	2.123265
S25	2.652245	1.065306	0.800816	1.792653
S26	2.916735	1.065306	0.800816	1.924898
S27	2.916735	1.065306	2.123265	2.255510
S28	0.800816	6.355102	0.800816	2.189388
S29	1.065306	7.677551	5.032653	3.710204
S30	0.536327	3.445714	4.239184	2.189388
S31	0.536327	7.677551	7.677551	4.106939
S32	1.329796	9.000000	3.181224	3.710204
S33	0.800816	7.677551	8.735510	4.503673
S34	1.594286	7.942041	9.000000	5.032653
S35	2.387755	8.206531	8.735510	5.429388

j / i	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35		
S1	0	0	1	0	0	1	0	0	1	0	1	1	1	0	0	0	0	0	1	1	1	0	0	1	1	1	1	1	0	0	0	1	0	0	0	15	
S2	1	0	1	0	0	1	1	1	1	0	1	1	1	0	0	1	1	0	1	1	1	0	0	1	1	1	1	1	1	1	0	1	0	0	0	22	
S3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	3	
S4	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	29	
S5	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	27	
S6	0	0	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	0	0	1	1	1	1	1	0	0	0	1	0	0	0	13	
S7	1	0	1	0	0	1	0	0	1	0	1	1	1	0	0	1	0	0	1	1	1	0	0	1	1	1	1	1	0	1	0	1	0	0	0	18	
S8	1	1	1	0	0	1	1	0	1	0	1	1	1	0	0	1	1	0	1	1	1	0	0	1	1	1	1	1	1	1	0	1	0	0	0	22	
S9	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	8	
S10	1	1	1	0	0	1	1	1	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	25	
S11	1	0	1	0	0	1	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	0	0	1	1	1	1	1	0	0	0	1	0	0	0	15	
S12	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	6	
S13	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	1	1	1	0	0	1	1	1	1	1	0	0	0	1	0	0	0	13	
S14	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	31	
S15	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	31	
S16	1	0	1	0	0	1	1	0	1	0	1	1	1	0	0	0	0	0	1	1	1	0	0	1	1	1	1	1	0	1	0	1	0	0	0	18	
S17	1	0	1	0	0	1	1	0	1	0	1	1	1	0	0	1	0	0	1	1	1	0	0	1	1	1	1	1	1	1	0	1	0	0	0	20	
S18	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	26	
S19	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	6	
S20	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0	1	1	1	1	1	0	0	0	1	0	0	0	11	
S21	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	1	0	0	0	1	1	1	1	1	0	0	0	1	0	0	0	11	
S22	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	0	1	0	0	0	25	
S23	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	0	1	0	0	0	25	
S24	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	6	
S25	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	3	
S26	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	3	
S27	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	8	
S28	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	3	
S29	1	0	1	0	0	1	1	0	1	0	1	1	1	0	0	1	0	0	1	1	1	0	0	1	1	1	1	1	0	1	0	1	0	0	0	19	
S30	1	0	1	0	0	1	0	0	1	0	1	1	1	0	0	0	0	0	1	1	1	0	0	1	1	1	1	1	0	0	0	1	0	0	0	16	
S31	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	29	
S32	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	12	
S33	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	33	
S34	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	34	
S35	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	33	619
	20	13	34	6	7	22	17	13	27	11	20	30	22	3	5	17	14	8	30	25	25	12	11	30	34	34	27	34	15	18	6	25	2	0	2		
																																			619		

Figure 6. People HSIM demonstrating the pairwise connection between the systems.

Table 3. Normalized weights for constituent systems.

	Normalised Values	**Rearranged (Normalised Values)**			**Effective Minimum Management Score Required for Competitiveness Attainment**
NotS1	**0.028456**	0.028032			
S2	0.028881	0.028063			
S3	0.028032	0.028120			
S4	0.028955	0.028199			
S5	0.028526	0.028199			
S6	0.028378	0.028223			
S7	0.028293	0.028223	Below	Count: 13	
S8	0.028591	0.028247		Percentage: 37.14%	0.136507
S9	0.028199	0.028293		Sum: 0.367519	
S10	0.028607	0.028378			
S11	0.028799	0.028456			
S12	0.028695	0.028526			
S13	0.028681	0.028559			
S14	0.028903	0.028591			
S15	0.028786	0.028607			
S16	0.028559	0.028607			
S17	0.028681	0.028652			
S18	0.028799	0.028652			
S19	0.028652	0.028652			
S20	0.028607	0.028652			
S21	0.028823	0.028652			
S22	0.028652	0.028681			
S23	0.028652	0.028681			
S24	0.028199	0.028695	Above	Count: 22	
S25	0.028063	0.028735		Percentage: 62.86%	0.397559
S26	0.028120	0.028786		Sum: 0.632481	
S27	0.028247	0.028799			
S28	0.028223	0.028799			
S29	0.028652	0.028811			
S30	0.028223	0.028823			
S31	0.028735	0.028881			
S32	0.028652	0.028903			
S33	0.028811	0.028903			
S34	0.028903	0.028955			
S35	0.028965	0.028965			
Average		0.028571			0.534067

5. Conclusions

Management efforts required to sustain the existence of complex systems are rarely expressed from a metricative point of view. due to their extreme qualitative nature. This research has. however. presented an approach for quantifying the management effort required in the sustainability of complex systems through algorithmic perception. measurement. effective planning. and decision-making. all aimed at enhancing the overall competitiveness of a SoS setup. such as the agro-seed processing industry. with GSA as the centric system. The SoS network was architected to show the complexities of the interactions between constituent systems. Thereafter. the HSIM concept was utilized to illustrate priority ordering via normalized weight determination for the 35 constituent systems identified in the case study. This study aims to establish a metric system for quantifying management effort in an environment where the SoS traditionally consists of a chain of embedded and interconnected non-metric qualitative tasks and activities. Instead of trying to improve overall management competitiveness through trial-and-error approaches. this study aims to identify. sense. and measure the priority systems that will increase the overall competitiveness the most. A future study related to this research would include the addition of more contextual questions deployed towards decision-making for the virtual and physical interactions between constituent systems. Furthermore. the specific rules that govern each level of competitiveness (by reflecting the necessary actions to be carried out and adhered to in order to maintain or enhance the competitiveness level) would be proffered in a more comprehensive version of this paper.

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