Transdisciplinary Methodology for Refugee Resettlement Process

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Abstract:*This paper's primary goal is to present a novel transdisciplinary (TD) methodology for the resettlement of refugees. Numerous factors, such as budgetary and cost concerns, federal law and policy, administrative difficulties, security screening protocols, education and training, housing and health, crime rate, socioeconomic issues, and many more, can be considered that influence the refugee resettlement process, showing that refugee resettlement is a complex matter. Using the Interactive Collective Intelligent Management (ICIM) Workshop, a working group developed transdisciplinary collective intelligence to investigate the issue. The Nominal Group Technique (NGT) was used to develop and clarify a list of issues about refugee resettlement through a survey. A condensed example of refugee resettlement that has ten TD solutions and six complex issue challenges created with ICIM is presented in this paper. TD integrated tools and TD solutions are applied to systematically understand, create, and manage effective administrative processes for addressing the challenging and interrelated issues associated with refugee resettlement.*

Keywords:Transdisciplinary, refugee resettlement, Integrated TD tools, complexity of refugee resettlement.

1 Introduction

Numerous factors, including war and civil unrest, violations of human rights, economic, social, political, environmental, and climatic shifts, cause people to relocate. It can be challenging to distinguish between the necessity of leaving (***migration***) and the option to do so (***forced displacement***) in such complicated circumstances. In 2018, the global population of *forcibly displaced* increased by 2.3 million, reaching 70.8 million. This means that 20 people are displaced globally every minute of the day (refer to Figure 1). From 43.3 million in 2009 to 70.8 million in 2018, the number of people who were forcibly relocated worldwide increased significantly and reached a record high. This increase occurred between 2014 and 2015, primarily as a result of the Syrian conflict as well as other regional conflicts in Sudan, Yemen, Iraq, and other impoverished nations. It is challenging to comprehend the worldwide refugee crisis due to the complexity of the subject. Resettlement of refugees is a complicated issue with many variables to take into

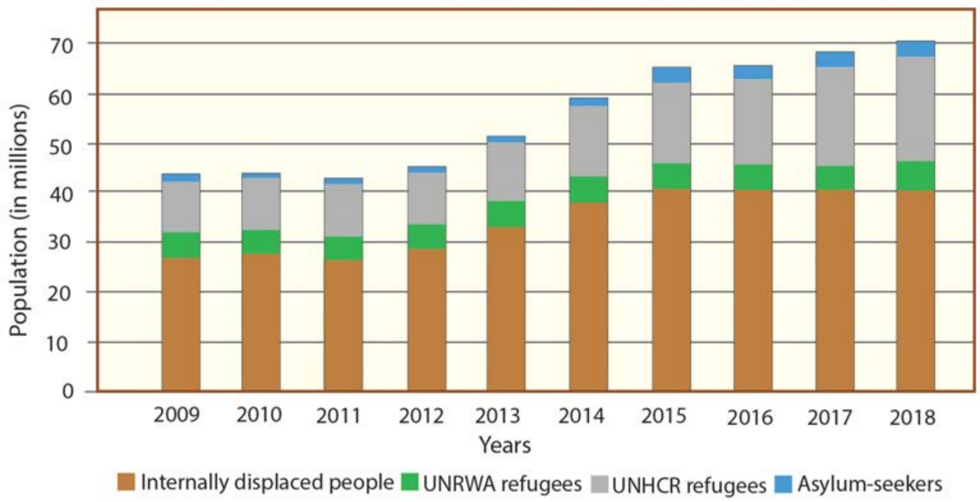


Figure 1: Global forced displacement during 2009-2018 (recreated from (UNHCR, 2020)). .

account. Many factors, such as budget and cost issues, federal law and policies, administrative challenges, security screening procedures, education and training, health and housing, crime rate, socioeconomic issues, and many more, are being taken into consideration for their potential impact on resettlement. Using transdisciplinary integrated design tools, the goal of this case study is to explore the relationships and interactions between the previously mentioned factors (Moran, et al., 2020).

Transdisciplinary tools used in this case study have been applied in many fields including product development, project management, many engineering disciplines, design of the organization, sustainable development, social issues, environmental issues, and others across many industries including automotive, aerospace, telecom, semiconductor, defense, transportation, energy, healthcare, agriculture, and more – the integration of well-known Transdisciplinary tools such as Quality Function Deployment (QFD), House of Quality (HOQ), TRIZ, Interpretive Structural Modeling (ISM), Design Structure Matrix (DSM), and Axiomatic Design (AD) addressing a wide range of domains will be included in this case study.

2 Transdisciplinary Tools Integration

The integrated TD design tools can be used in a wide range of domains. This case study shows a new framework for integrated TD tools (see Figure 2) which has great potential benefits for solving large-scale complex problems. Complex problems could be large-scale product development or solving societal complex issues– in both cases, we use a generic term called "***issue***" in hand to be solved.

2.1 Integrating QFD and TRIZ

Contradictions are a common feature of complex issues, which are typically resolved by compromises or trade-offs between the two parameters of the complex issue. By resolving contradictions in the problem-solving of a complex issue, the *TRIZ inventive problem solving* can be used to eliminate compromises—the contradiction resolution is more innovative than any other trade-off solution.

As shown in Figure 3, the TRIZ method offers a wide array of applications in QFD (Tursch, et al., 2015). QFD and TRIZ have complementary approaches and different viewpoints for product development and planning. Figure 4 illustrates the level of impact and relationships of QFD and TRIZ on certain requirements of product development (Terninko, et al., 1998).

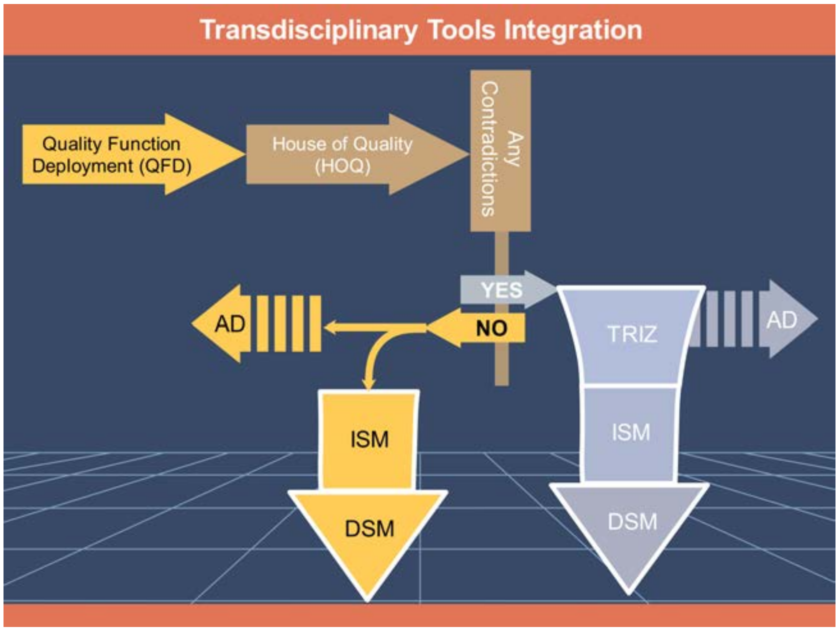


Figure 2: Framework of integrated TD tools.

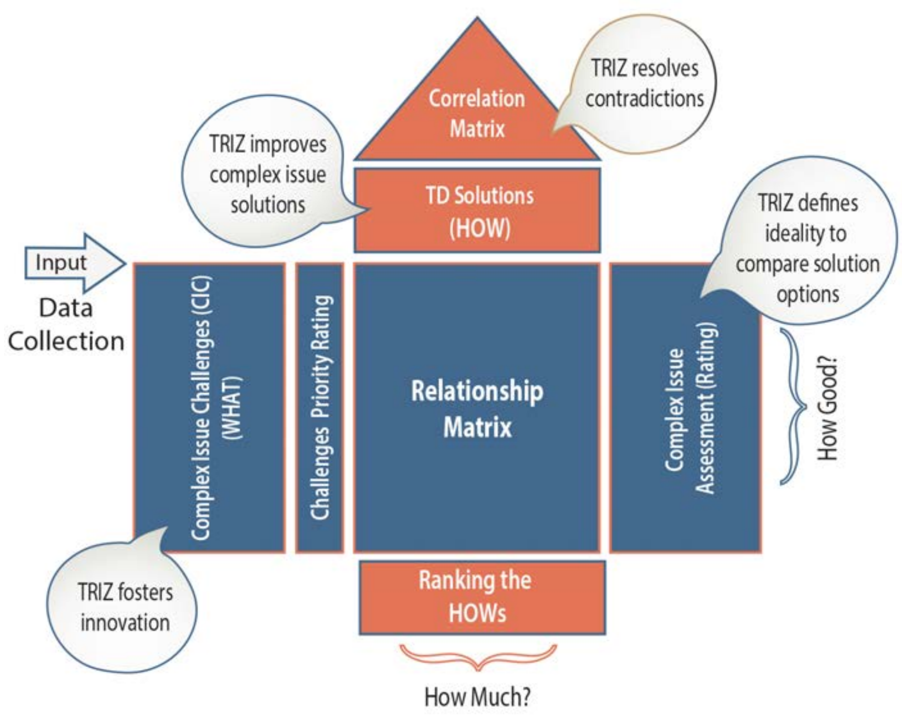


Figure 3: TRIZ application in HOQ (adapted from reference [1]).

The Innovative Product Development Process (IPDP), created by Hajime et al., allows for the efficient and methodical generation of technical innovation for new products by methodically integrating QFD and

Ranking	
Strong Relationship	XXX
Medium Relationship	XX
Weak Relationship	X

	QFD	TRIZ
Customer Satisfaction	XXX	X
Product Quality	XXX	XXX
Profits	XXX	XXX
Market Share	XXX	XXX
Innovation	XX	XXX
Failure Anticipation		XXX
Intellectual Capital Protection		XXX
Technological Prospection		XXX

Figure 4: QFD and TRIZ synergy (from reference 3).

TRIZ (Yamashina, et al., 2002). In addition to meeting customer demands, the integration of TRIZ and QFD capabilities enables the development of solutions based on technological systems that offer completely new user experiences (Naveiroa, et al., 2018).

The HOQ identifies relationships among the issue challenges and interactions between the TD solutions of the complex problem. TRIZ through the contradiction matrix solves the main shortcoming of the QFD method when the TD solution of the complex issues conflict with each other. The conflicts between TD solutions of complex issues that appeared in the HOQ correlation matrix may be eliminated by using the TRIZ inventive principles. The following procedures (see Figure 5) can be used to find TD solutions for conflicting problems that are present in the HOQ using TRIZ:

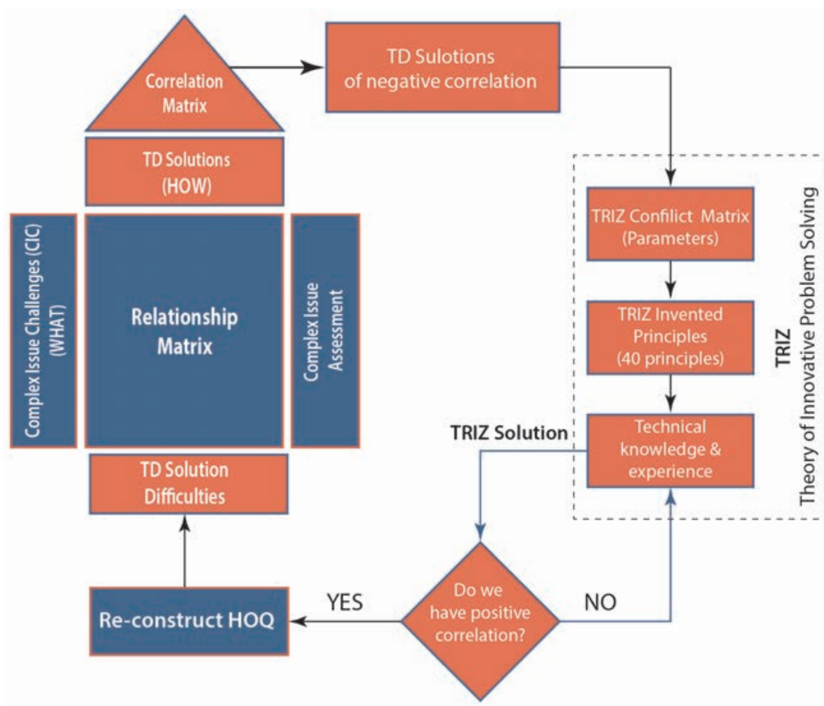


Figure 5: Flow chart.

1. Identify the conflicting TD solutions with negative correlation in the HOQ correlation matrix.

2. Identify the TD solution's type, which one is improving and which one is worsening characteristics.
3. Replace the TD solutions' with corresponding parameters from TRIZ 39 contradiction matrix.
4. Using contradiction matrix tables, identify which of the 40 inventive principles are applicable to your problem to resolve the contradiction.
5. After brainstorming, adapt the appropriate solution from 40 inventive principles to resolve the conflict among the TD solutions in the HOQ correlation matrix.
6. Re-construct the HOQ with the new TD solutions.

3 Challenges of Managing Refugee Resettlement

Any government that offers asylum to any displaced person wants to see refugees successfully resettled. Resettlement can be defined as the process of integrating refugees into the host society with the help of the government, to eventually become self-sufficient and mark the end of government assistance as the completion point. The elements of administration and programming that are thought to be most crucial to the economic independence of refugees. Although it is known that refugees have been successful in finding work, there are still significant obstacles in the way of achieving economic independence. Some of these obstacles are similar to those that low-income participants in mainstream programs encounter. Language barriers, transportation problems, resource constraints, and difficult-to-serve clients are among the most prevalent challenges (Halpern, 2008).

Transdisciplinary cooperation between and within institutional sectors in the receiving countries is necessary for immigrants to be accepted and integrated successfully into their new home countries. Organizations like social services, education, the government, community-based organizations, and others need to collaborate and join forces.

Resettlement of refugees is a complicated issue with many variables to take into account. To look into the problem, the working group created transdisciplinary collective intelligence using the Interactive Collective Intelligent Management (ICIM) Workshop. Through the survey, a list of issues affecting the complex issue was developed and clarified using the Nominal Group Technique (NGT) (Delbecq and Vandeven, 1971).

About 20 people from a range of backgrounds, including past refugees, volunteers for refugee relief, mechanical and systems engineers, system integrators, leads of non-profit organizations, salespeople for construction materials, current humanitarian workers, international business executives, world travelers, and former military personnel with extensive work oversees, were chosen to participate in the survey (Moran, et al. 2021).

A working group that included two Ph.D. candidates, one design faculty member, and twenty-five senior design class undergraduate students from Texas Tech University who were all pursuing degrees in mechanical engineering took part in the ICIM. The working group created a set of difficult elements for complicated refugee settlement issues, demonstrating how certain aspects of the issue they found were connected to the transdisciplinary solutions created during the ICIM. The workshop was led by a Ph.D. student who has experience with the ICIM.

3.1 Quality Function Deployment (QFD)

Figure 6 illustrates the QFD of a simplified refugee resettlement example with six challenges and ten TD solutions developed using ICIM. To pinpoint the areas that require improvement and attention, the case study defines strong, medium, and weak relationships between the complex issue challenges and the TD solutions. There is no relationship between the TD solutions and the complex issue challenges if the cells are blank. Language barriers (41) and self-sufficiency (45) received the highest scores for the complex issue challenges, as indicated in Figure 6. Education (28) and limited federal funding (30) received the highest scores for TD solutions. The improvement of the high-scoring areas will be the main focus of decision-making efforts in order to meet the challenges posed by complex issues.

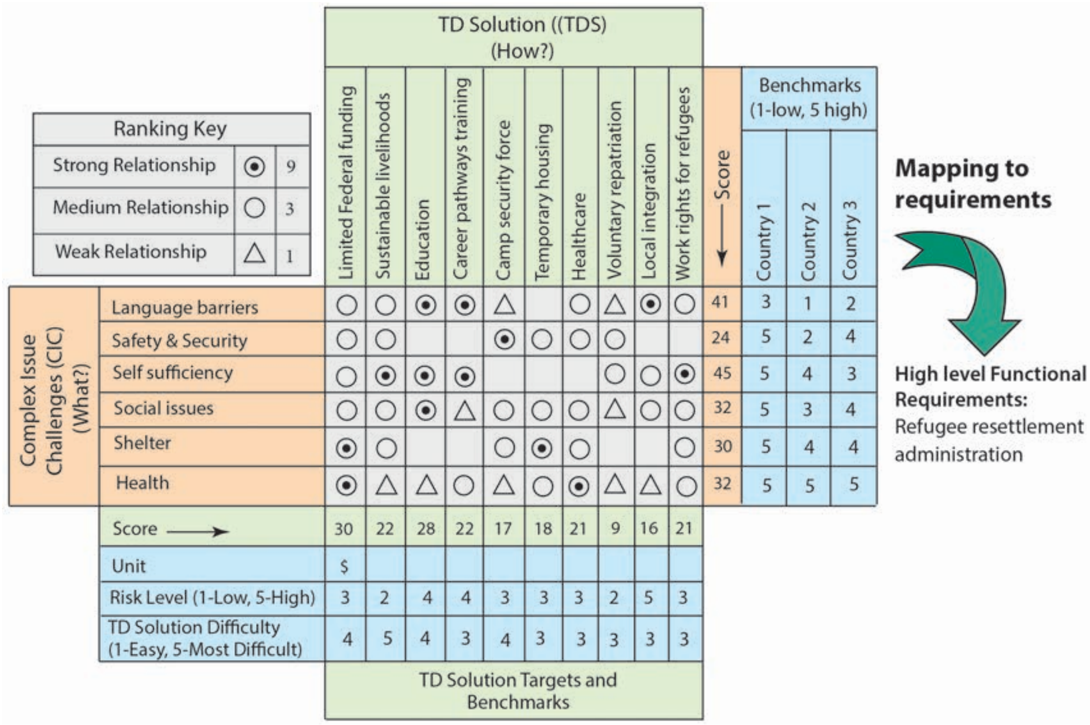


Figure 6: Refugee resettlement challenges and TD solutions (QFD).

The TD solutions to meet the challenges are:

- **Limited Federal funding:** Federal funding is limited in both duration and amount.
- **Sustainable livelihood:** Through the creation of jobs for low-income households and the elimination of highly vulnerable households, the Livelihood Program seeks to reduce poverty and promote sustainable livelihoods for long-term economic stability.
- **Education:** For refugees to adapt and establish a life for themselves in society, education and training programs are essential. In the absence of these initiatives, refugees are forced to survive on their own in a society they are most likely very unfamiliar with.
- **Career pathway training:** is a series of integrated, structured education and training programs designed to help people become better over time.
- **Camp security force:** Securing refugee populations' living quarters or averting threats to their safety are necessary to safeguard their physical security.
- **Temporary housing:** is built as a temporary home for victims who have lost or abandoned their homes as a result of a conflict or natural disaster.
- **Healthcare:** program for refugees is governed by the government of the host country. The host nation's health insurance programs provide access to health insurance for refugees who are accepted by the government.
- **Voluntary repatriation:** is the voluntary return of refugees to their country of origin after it has been determined that conditions there are safe. When circumstances have improved and the government of the refugee's home country guarantees their protection, refugees are typically asked to return voluntarily.

- **Local integration:** is an ongoing, intricate process that takes into account social, legal, economic, and cultural aspects. Local integration is fraught with difficulties and requires a great deal of work on the part of both the receiving society and the refugees.
- **Work rights for refugees:** "For refugees the right to work and access to labor markets is key for becoming self-reliant, rebuilding their lives and securing dignity, and allowing them to contribute to their host communities. To this end, articles 17-19 of the 1951 Convention relating to the Status of Refugees provide opportunities for wage-earning employment, self-employment, and employment in liberal professions" (Schuettler, 2017).

3.2 Refugee Resettlement Challenges and TD Solutions of HOQ

The HOQ matrix resembles a house with a *correlation matrix* as its roof, as seen in Figure 7. Just like QFD, it links TD solutions to complex issue challenges using a relationship matrix.

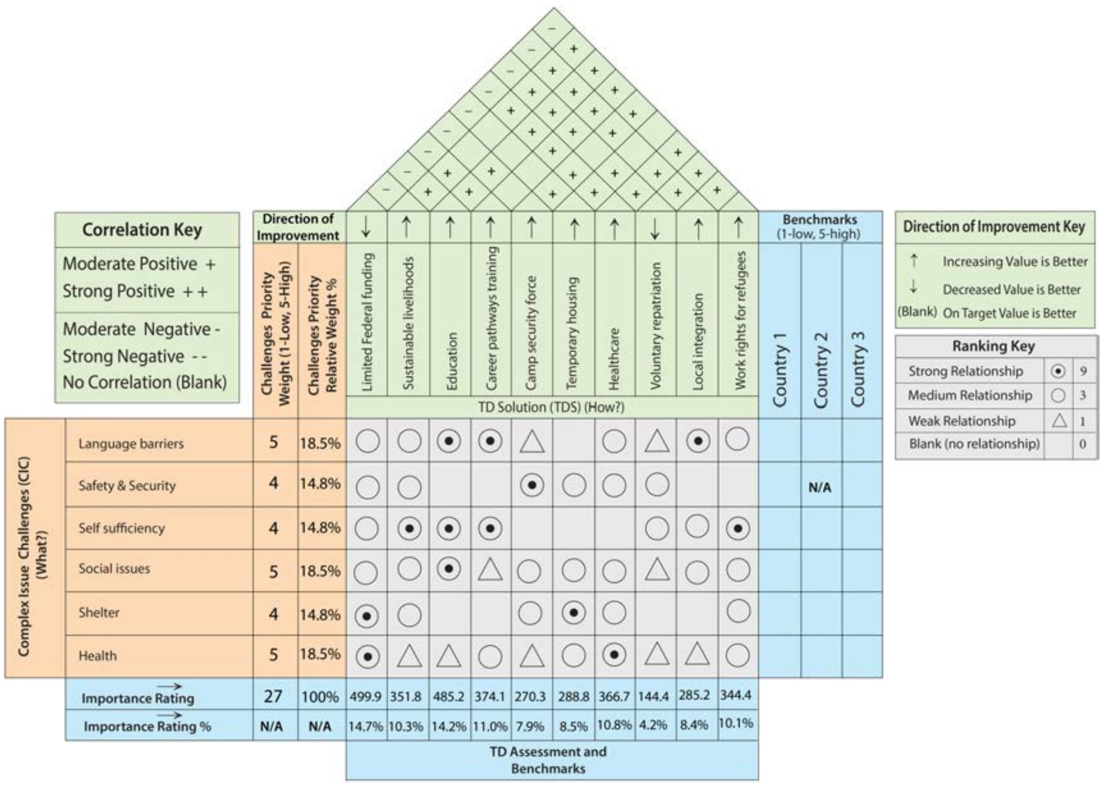


Figure 7: Refugee resettlement challenges and TD solutions (HOQ).

Figure 7 illustrates the direction of improvement. For instance, lower limited federal funding is preferable if all other TD solutions remain unchanged (management should not exceed the total budget allocated for the project). According to the HOQ analysis, the administration's successful management of refugee resettlement is largely due to the restricted federal funding, which has the highest importance rating. Considerable attention should be paid to this crucial issue point in the administration of refugee settlement and the decision-making procedure.

The correlation matrix is used to determine whether the TD solutions in the refugee settlement complex issue support or contradict one another, as Figure 7 illustrates. Except for "limited federal funding," all of the TD solutions in this case study have a positive mutual impact. Better educational programs for refugees, for instance, facilitate their "local integration" with the host community more quickly. However, a moderate negative correlation can be seen in the correlation matrix as a result of the improvement of ”sustainable livelihoods” leading to an increase in ”limited federal funding.”

”Limited federal funding” is the worsening characteristic in this instance, while ”sustainable livelihoods” is the improving one. Put another way, it might be more expensive to enhance ”sustainable livelihoods” than the limited amount of federal funding allotted. TRIZ can be used to design out the detrimental effects of ”limited federal funding” on the other TD solutions.

The problem of cost is one that many people struggle with because it is a common discussion point for any significant project. However, many TRIZ techniques don’t specifically address cost. Some of the same parameters that drive up costs in the TRIZ matrix identified by Darrell Mann (2004) can be used to replace cost. They are:

- Complexity of the system
- Complexity of control
- System-generated harmful factors
- Time and risk issues for the R&D, production, supply, and support
- Speed of a process
- Duration of action
- Loss of energy, loss of material, loss of information, loss of time
- Reliability
- System-generated harmful factors
- Ease of operation
- Ease of manufacturing
- Ease of repair
- System/device complexity
- Extent of automation
- Productivity

Based on the previously provided information regarding the factors that lead to the cost of ”limited federal funding” rising, we identify ”complexity of the system (36)” as a worsening characteristic and ”reliability (27)” as an improving characteristic for ”sustainable livelihoods.” From the TRIZ matrix of contradictions (see Table A1 in Appendix), at the intersection of the two characteristics (see Figure 8) the following three potential solutions principles (see Table A2 in Appendix) are possible: (13) Inversion, (35) Parameter change, and (1) Segmentation.

Solution 13: The other way around

- Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it).
- Make movable parts (or the external environment) fixed, and fixed parts movable.
- Turn the object (or process) ’upside down

Solution 35: Parameter changes

- Change an object’s physical state (e.g. to a gas, liquid, or solid.)
- Change the concentration or consistency.
- Change the degree of flexibility.
- Change the temperature.

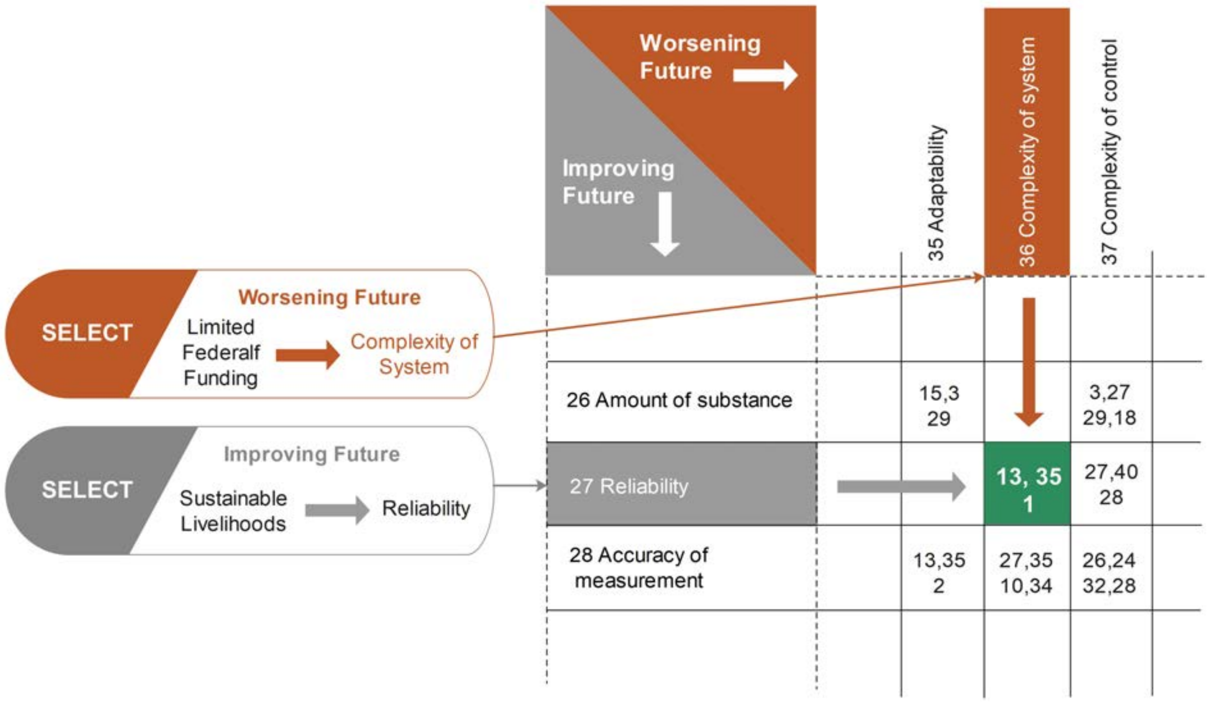


Figure 8: TRIZ potential principles solutions.

Solution 1: Segmentation

- Divide an object into independent parts.
  - (a) Replace mainframe computer with personal computers.
  - (b) Replace a large truck with a truck and trailer.
  - (c) Use a work breakdown structure (WBS) for a large project.

Decision: Among the other solutions proposed for this case study, “Segmentation (b)” (1) will result in a solution. The conflict between ”limited federal funding” and ”sustainable livelihoods” will be resolved by this solution. Note that all other contradictions will vanish when ”limited federal funding” is replaced with ”work breakdown structure (WBS).”

U.S. Department of Energy defines WBS as “A WBS is the cornerstone of effective project planning, execution, controlling, and reporting. All the work contained within the WBS is to be identified, estimated, scheduled, and budgeted. The WBS is the structure and code that integrates and relates all project work (scope, schedule, and cost)” [11].

3.2.1 Re-build HOQ

To rebuild the HOQ, the relationships between the TD solutions and this new ‘WBS” characteristic need to be carefully considered. Keep in mind that the contradiction and correlation matrices need to be updated. It’s also necessary to recalculate the importance rating. The Figure 9 displays the updated rebuilt HOQ.

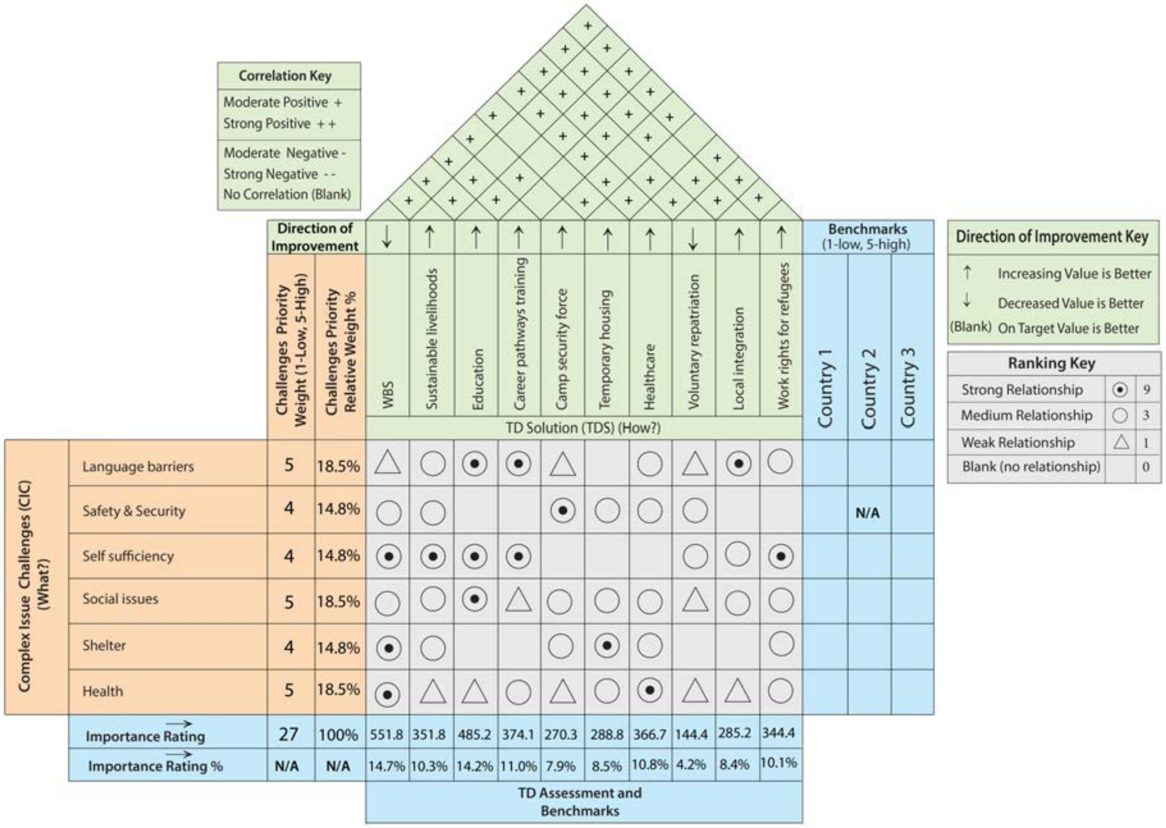


Figure 9: Rebuilt HOQ.

3.2.2 Discussions

How the House of Quality assists with the administrative procedures involved in refugee resettlement is a pertinent question to pose. The creation of HOQ marks the beginning of TD activity. Experts from various domains (cross-functional teams) collaborate to create a list of TD solutions and challenges related to refugee resettlement during this first phase. These solutions are then used to build and prioritize a range of specific actions for the process of resettling refugees, thereby maximizing their potential in the host nation. HOQ matrix connecting the challenges with refugee resettlement and the TD solutions. This helps the cross-functional team make the key tradeoffs between the refugee resettlement challenges and the TD solutions to develop an administrative process that will have a major impact on the complex refugee resettlement challenges.

The correlation matrix's primary features are supplied by the House of Quality. The TD solutions are mapped to one another in the correlation matrix (roof) to determine which ones support (positive correlation) or contradict (negative correlation) one another. It doesn't, however, specifically state how they influence one another. With the help of specialists who are knowledgeable about the background of the TD solutions related to refugee resettlement, Interpretive Structural Modeling (ISM), a technique, will be utilized to address this problem and establish the directional relationships between TD solutions.

3.3 Integrating Rebuilt HOQ with ISM

As seen in Figure 10(b), TD Solutions from the rebuilt HOQ will be used as the factors affecting the difficult problem of refugee resettlement in ISM.

We live in a highly complex, technological world – and it's not entirely obvious what's right and what is wrong in any given situation unless you can parse the situation, and deconstruct it. People just don't have the insight to be able to do that very effectively.

Christopher Langan

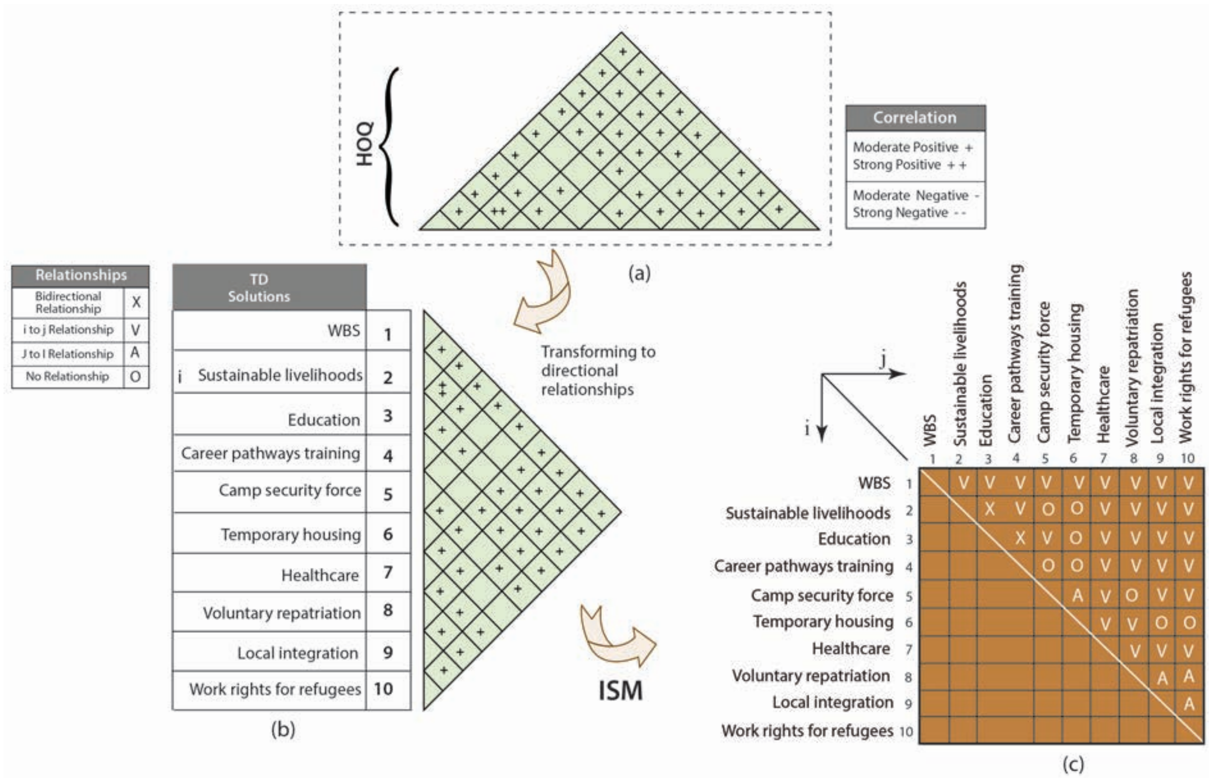


Figure 10: Transforming HOQ to directional relationships (SSIM).

A group of parts (elements) illustrating their connections in a network diagram with nodes and the links between them is called a *structural model*. By examining a structural model of the system's constituent parts, we can use structural modeling to obtain a comprehensive understanding of the system as a whole. According to Warfield (Warfield, 1974), structural modeling is:

> "Structural modeling is a methodology which employs graphics and words in carefully defined pattern to portray the structure of a complex issue, a system, or a field of study."

In complex, real-world settings, *Interpretive Structural Modeling* (**ISM**) is an efficient methodology to handle new, ill-defined problems. It is a transdisciplinary tool used in many different human endeavors to help comprehend complex situations that arise in a variety of knowledge domains, including managing organizations, designing large-scale systems, and creating plans.

ISM finds connections between particular elements that are pertinent to the issue or problem. This makes it easier for researchers to organize a variety of distinct but closely connected variables (parameters) that impact the system into a thorough hierarchical model, which in turn helps to define conceptual system models that are ambiguous or poorly expressed. A complex issue is broken down into smaller sub-issues and an easily understandable multilevel structural model is constructed using experts with practical experience and knowledge from a variety of knowledge domains (academic and non-academic). This is the fundamental approach of the ISM process.

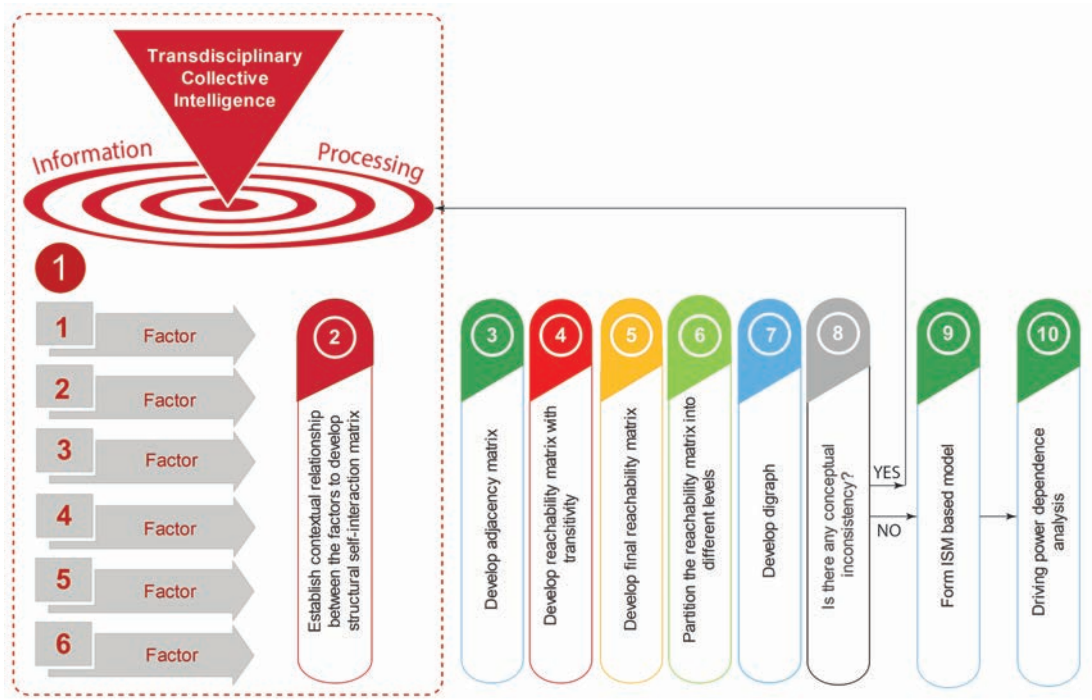


Figure 11: ISM process.

3.3.1 ISM Process

The following procedures are taken in order to develop the ISM process, as Figure 11 illustrates.

3.3.2 Structural Self-Interaction Matrix

The process of developing a Structural Self-Interaction Matrix (SSIM), as illustrated in Figure 10(c), begins with defining the TD solutions (factors). Subsequently, a contextual relationship between the TD solutions is established. The participants in the transdisciplinary collective intelligence workshop will choose the pairwise relationship between the TD solutions during this phase. Through discussion and debate, the workshop participants will determine the contextual relationship for each TD solution, the relationship between any two TD solutions (i and j), and the associated direction of the relation. The following list contains the four symbols that are used to show which way the TD solutions i and j are related:

- V = for the relation from i to j but not in both directions;
- A = for the relation from j to i but not in both directions;
- X = for both-direction relations: from i to j and j to i; and
- O= if the relation between the elements does not appear to be valid

3.3.3 Adjacency Matrix

To create the adjacency matrix R_a, which is depicted in Figure 12, SSIM must be converted into a binary matrix by replacing V, A, X, and O with 1 and 0.

$R_a =$

		1	2	3	4	5	6	7	8	9	10
WBS	1	1	1	1	1	1	1	1	1	1	1
Sustainable livelihoods	2	0	1	1	1	0	0	1	1	1	1
Education	3	0	1	1	1	1	0	1	1	1	1
Career pathways training	4	0	0	1	1	0	0	1	1	1	1
Camp security force	5	0	0	0	0	1	0	1	0	1	1
Temporary housing	6	0	0	0	0	1	1	1	1	0	0
Healthcare	7	0	0	0	0	0	0	1	1	1	1
Voluntary repatriation	8	0	0	0	0	0	0	0	1	0	0
Local integration	9	0	0	0	0	0	0	0	1	1	0
Work rights for refugees	10	0	0	0	0	0	0	0	1	1	1

Figure 12: Adjacency matrix.

$R_t =$

		1	2	3	4	5	6	7	8	9	10
WBS	1	1	1	1	1	1	1	1	1	1	1
Sustainable livelihoods	2	0	1	1	1	1	0	1	1	1	1
Education	3	0	1	1	1	1	0	1	1	1	1
Career pathways training	4	0	1	1	1	1	0	1	1	1	1
Camp security force	5	0	0	0	0	1	0	1	1	1	1
Temporary housing	6	0	0	0	0	1	1	1	1	1	1
Healthcare	7	0	0	0	0	0	0	1	1	1	1
Voluntary repatriation	8	0	0	0	0	0	0	0	1	0	0
Local integration	9	0	0	0	0	0	0	0	1	1	0
Work rights for refugees	10	0	0	0	0	0	0	0	1	1	1

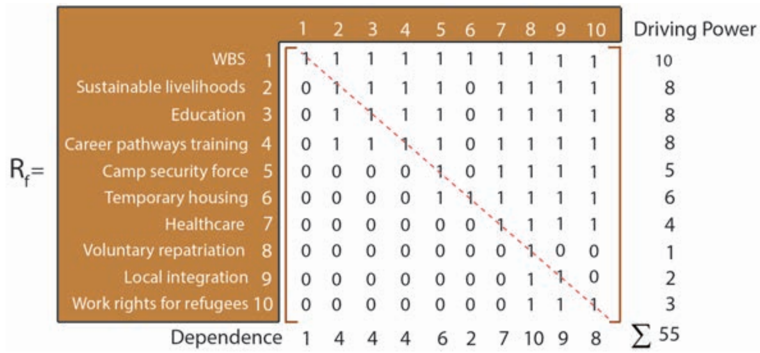
Figure 13: Reachability matrix with transitivity.

3.3.4 Reachability Matrix with Transitivity

Transitivity in the reachability matrix is displayed in Figure 13. The transitivity rule is checked for in the reachability matrix, and it is updated until transitivity is verified. "If **A** is related to **B** and **B** is related to **C**, then **A** is related to **C**" is the transitive rule. A reachability matrix is created by applying the transitivity rule, as seen in Figure 13.

3.3.5 Final Reachability Matrix

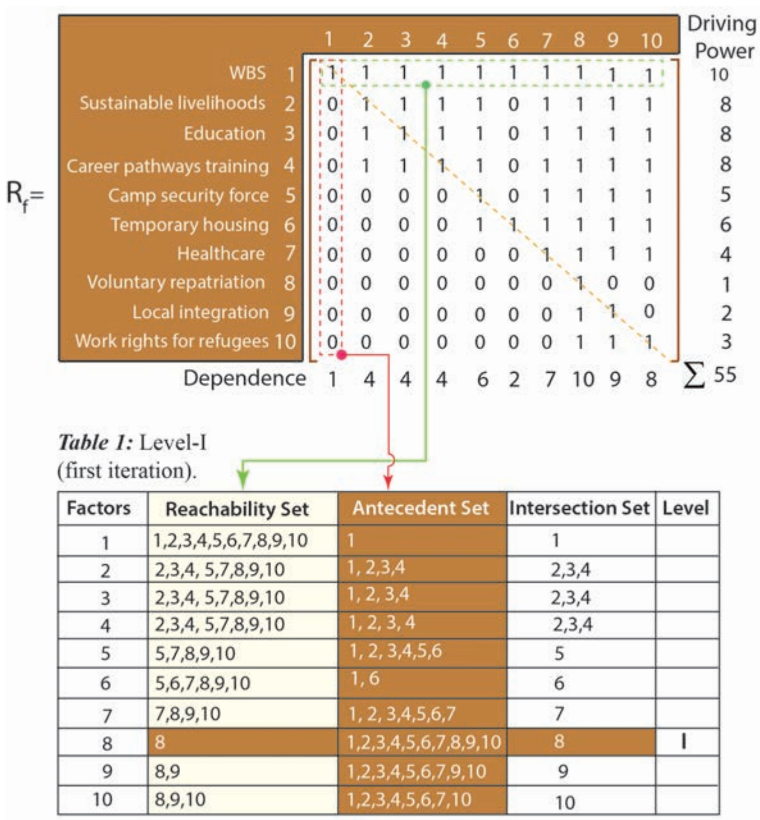
Figure 14's *Final reachability matrix* displays the *Dependency* and *Driving power* of the factors. The driving force and dependence are respectively calculated as the sum of the ones in the corresponding rows and columns. The final form of all the factors' relationships with the problem under consideration is shown in Figure 14. MICMAC analysis will make use of the driving power and dependence calculations shown in Figure 14.



$R_f=$

		1	2	3	4	5	6	7	8	9	10	Driving Power
WBS	1	1	1	1	1	1	1	1	1	1	1	10
Sustainable livelihoods	2	0	1	1	1	1	0	1	1	1	1	8
Education	3	0	1	1	1	1	0	1	1	1	1	8
Career pathways training	4	0	1	1	1	1	0	1	1	1	1	8
Camp security force	5	0	0	0	0	1	0	1	1	1	1	5
Temporary housing	6	0	0	0	0	1	1	1	1	1	1	6
Healthcare	7	0	0	0	0	0	0	1	1	1	1	4
Voluntary repatriation	8	0	0	0	0	0	0	0	1	0	0	1
Local integration	9	0	0	0	0	0	0	0	1	1	0	2
Work rights for refugees	10	0	0	0	0	0	0	0	1	1	1	3
Dependence		1	4	4	4	6	2	7	10	9	8	∑ 55

Figure 14: Final reachability matrix.



$R_f=$

		1	2	3	4	5	6	7	8	9	10	Driving Power
WBS	1	1	1	1	1	1	1	1	1	1	1	10
Sustainable livelihoods	2	0	1	1	1	1	0	1	1	1	1	8
Education	3	0	1	1	1	1	0	1	1	1	1	8
Career pathways training	4	0	1	1	1	1	0	1	1	1	1	8
Camp security force	5	0	0	0	0	1	0	1	1	1	1	5
Temporary housing	6	0	0	0	0	1	1	1	1	1	1	6
Healthcare	7	0	0	0	0	0	0	1	1	1	1	4
Voluntary repatriation	8	0	0	0	0	0	0	0	1	0	0	1
Local integration	9	0	0	0	0	0	0	0	1	1	0	2
Work rights for refugees	10	0	0	0	0	0	0	0	1	1	1	3
Dependence		1	4	4	4	6	2	7	10	9	8	∑ 55

Table 1: Level-I (first iteration).

Factors	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7,8,9,10	1	1	
2	2,3,4, 5,7,8,9,10	1, 2,3,4	2,3,4	
3	2,3,4, 5,7,8,9,10	1, 2, 3,4	2,3,4	
4	2,3,4, 5,7,8,9,10	1, 2, 3, 4	2,3,4	
5	5,7,8,9,10	1, 2, 3,4,5,6	5	
6	5,6,7,8,9,10	1, 6	6	
7	7,8,9,10	1, 2, 3,4,5,6,7	7	
8	8	1,2,3,4,5,6,7,8,9,10	8	I
9	8,9	1,2,3,4,5,6,7,9,10	9	
10	8,9,10	1,2,3,4,5,6,7,10	10	

Figure 15: Identifying level I.

3.3.6 Level Partition

The TD solutions were categorized using the driving force and dependence found in the final reachability matrix, as indicated in Tables 1 through 7. The development of Table 1, which presents Level-I of the first iteration, is demonstrated in Figure 15. Rows of R_f are used to identify the "Reachability Sets," and columns are used to identify the "Antecedent Set." The remaining tables are created using the same procedure. An intersection set is produced by the intersection of reachability sets and antecedent sets. Stated differently, the intersection set consists of the elements shared by the antecedent set and the reachability set. In the ISM hierarchy, a factor is designated as the top-level group (level I group) when

Table 1: Level-I (first iteration).

Factors	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7,8,9,10	1	1	
2	2,3,4, 5,7,8,9,10	1, 2,3,4	2,3,4	
3	2,3,4, 5,7,8,9,10	1, 2, 3,4	2,3,4	
4	2,3,4, 5,7,8,9,10	1, 2, 3, 4	2,3,4	
5	5,7,8,9,10	1, 2, 3,4,5,6	5	
6	5,6,7,8,9,10	1, 6	6	
7	7,8,9,10	1, 2, 3,4,5,6,7	7	
8	8	1,2,3,4,5,6,7,8,9,10	8	I
9	8,9	1,2,3,4,5,6,7,9,10	9	
10	8,9,10	1,2,3,4,5,6,7,10	10	

Delete factor 8 and level-I from the table for the next iteration.

Table 2: Level-II (second iteration).

Factors	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7,9,10	1	1	
2	2,3,4,5,7,9,10	1, 2,3,4	2,3,4	
3	2,3,4, 5,7,9,10	1, 2, 3,4	2,3,4	
4	2,3,4, 5,7,9,10	1, 2, 3, 4	2,3,4	
5	5,7,9,10	1, 2, 3,4,5,6	5	
6	5,6,7,9,10	1, 6	6	
7	7,9,10	1, 2,3,4,5,6,7	7	
9	9	1,2,3,4,5,6,7,9,10	9	II
10	9,10	1,2,3,4,5,6,7,10	10	

Delete factor 9 and level-II from the table for the next iteration.

Table 3: Level-III (third iteration).

Factors	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7,10	1	1	
2	2,3,4, 5,7,10	1, 2,3,4	2,3,4	
3	2,3,4, 5,7,10	1, 2, 3,4	2,3,4	
4	2,3,4, 5,7,10	1, 2, 3, 4	2,3,4	
5	5,7,10	1, 2,3,4,5,6	5	
6	5,6,7,10	1, 6	6	
7	7,10	1, 2,3,4,5,6,7	7	
10	10	1,2,3,4,5,6,7,10	10	III

Delete factor 10 and level-III from the table for the next iteration.

the factors of the intersection and reachability sets are equal. In order to determine the next level, the top-level factors are removed from the set after they have been identified. This iterative process is carried out repeatedly until all of the levels are identified, as shown in Tables 1 through 7. The ISM model and digraph will be constructed using these levels.

Table 4: Level-IV (fourth iteration).

Factors	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7	1	1	
2	2,3,4, 5,7	1,2,3,4	2,3,4	
3	2,3,4, 5,7	1,2,3,4	2,3,4	
4	2,3,4, 5,7	1,2,3,4	2,3,4	
5	5,7	1,2,3,4,5,6	5	
6	5,6,7	1, 6	6	
7	7	1,2,3,4,5,6,7	7	IV

Delete factor 7 and level-IV from the table for the next iteration.

Table 5: Levels-V (fifth iteration).

Factors	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6	1	1	
2	2,3,4,5	1,2,3,4	2,3,4	
3	2,3,4,5	1,2,3,4	2,3,4	
4	2,3,4,5	1,2,3,4	2,3,4	
5	5	1,2,3,4,5,6	5	V
6	5,6	1,6	6	

Delete factor 5 and levels-V from the table for the next iteration.

Table 6: Level-VI (sixth iteration).

Factors	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,6	1	1	
2	2,3,4	1,2,3,4	2,3,4	VI
3	2,3,4	1,2,3,4	2,3,4	VI
4	2,3,4	1,2,3,4	2,3,4	VI
6	6	1,6	6	VI

Delete factors 2, 3, 4, and 6 and levels-VI from the table for the next iteration.

Table 7: Level-VII (seventh iteration).

Factors	Reachability Set	Antecedent Set	Intersection Set	Level
1	1	1	1	VII

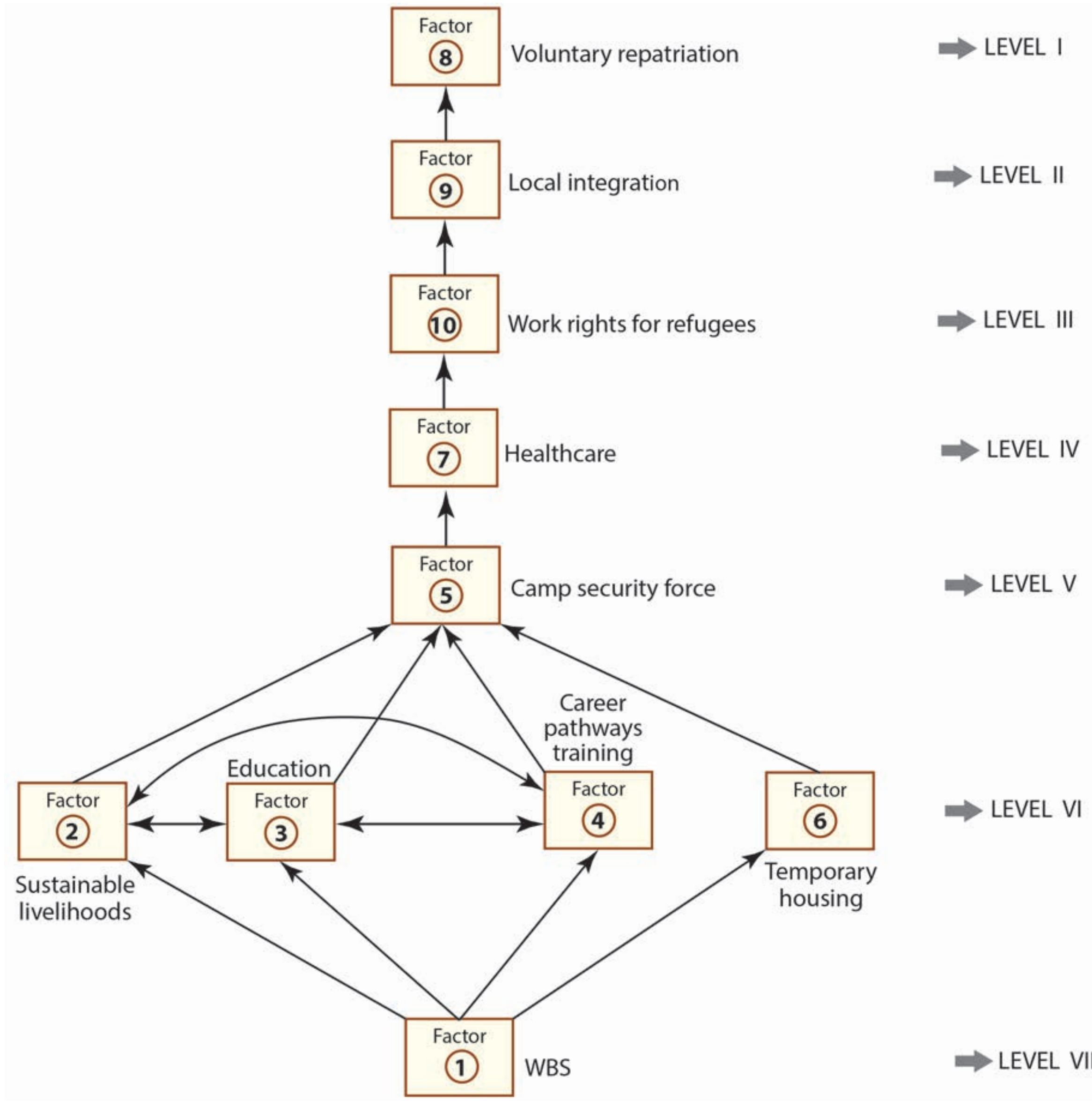


Figure 16: Digraph.

3.3.7 Formation of Digraph

A diagram known as a digraph illustrates the links between the parameters' direct and indirect relationships, including transitivity. The relationship between parameters and binary associations through matrices can now be represented graphically using the theory of digraphs, as seen in Figure 16 (Harary, F. et al., 1965). The direct and indirect relationships between the parameters influencing the effectiveness of managing refugee resettlement are visually represented in Figure 16. The previously obtained reachability matrix is divided into seven levels, as Figure 16 illustrates. A hierarchical structure is created by the levels being positioned so that lower levels can reach upper levels and by the transitivity and reachability of the relations connecting them. The top position of the hierarchical relations is indicated by the first level.

3.3.8 MICMAC Analysis:

To examine the driving force and dependence of the parameters affecting the problem at hand, Duperrin and Godet (1973) developed the MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée á un Classement) analysis. Figure 17 illustrates how TD solutions that impact refugee resettlement success are grouped into four clusters based on their dependence and driving force: (1) autonomous, (2) dependent, (3) linkage, and (4) independent factors. Each TD solution's driving power and dependence are imported from Figure 14. For instance, TD solution 1 is positioned in the upper left corner of the MICMAC diagram because its coordinates are Dependence = 1 and Driving power = 10.

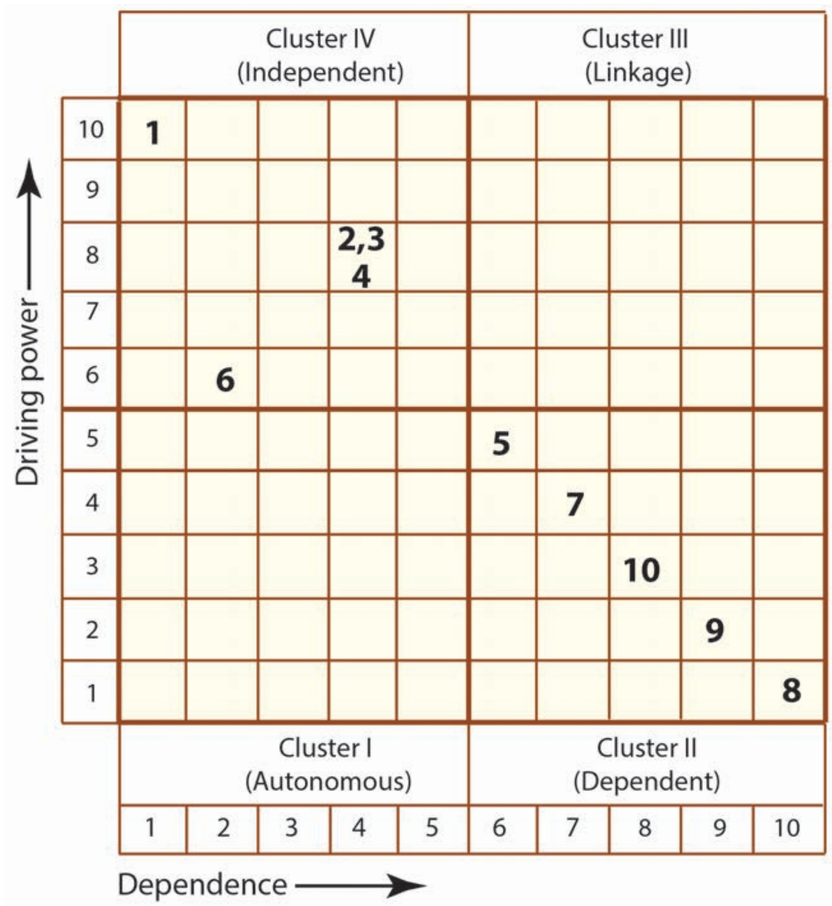


Figure 17: MICMAC Analysis.

3.3.9 Discussions

The ISM methodology is applied in this study to better understand and characterize the refugee resettlement administration process through the use of TD solutions, as well as to establish the hierarchical relationships among the TD solutions. The domain experts' assessment determines whether and how the various TD solutions are related to one another, making the ISM methodology interpretive.

It is significant to remember that judgments regarding the compatibility of the TD solutions are predicated on experience, familiarity with the resettlement of refugees, and subjective knowledge. Rather than focusing on individual TD solutions, the direct and indirect relationships among the TD solutions provide a more accurate description of the administration of refugee resettlement. Among the various TD solutions that support the resettlement administration process, we can determine which one has the greatest driving power through ISM analysis. We can also spot shaky TD solutions that might have a bad effect on the administration procedure.

3.4 Integrating ISM with DSM

The Design Structure Matrix (DSM), a transdisciplinary tool created by Steward in 1981, is combined with ISM and used to address the difficulties involved in managing refugee resettlement. According to Eppier S.D. and Browning, T.R. (2012), the Design Structure Matrix modeling method is a useful tool for modeling design complexities based on interactions. The transformation of the adjacency matrix from ISM to DSM is shown in Figure 18.

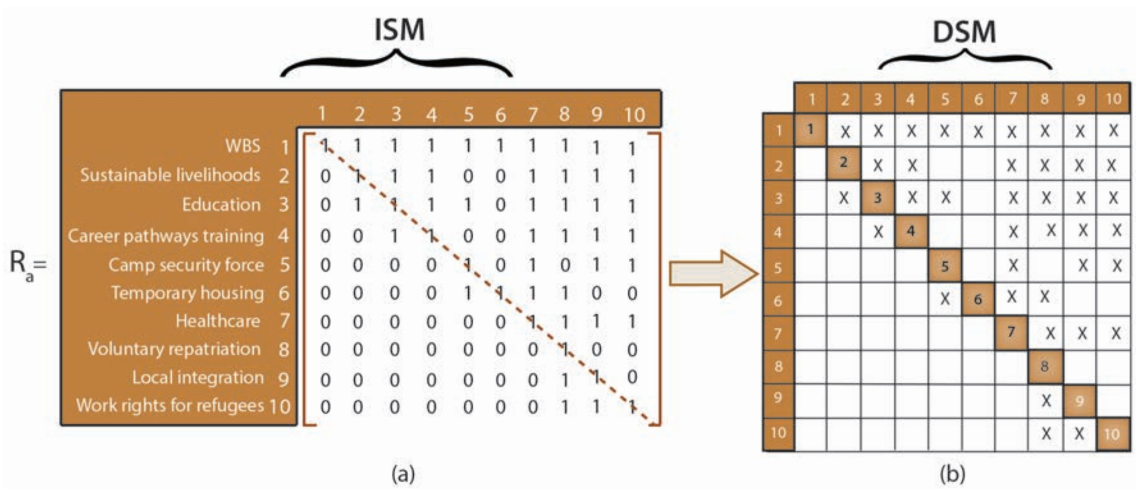


Figure 18: Transforming ISM to DSM.

In this research, managing refugee resettlement is modeled to analyze a management process at the level of parameter relationships—A parameter-based DSM that is constructed from a “bottom-up” approach to identify the low-level parameters (describes more specific individual parameters) that define the management process: It tracks critical system parameters through the design process to find the sequencing decisions of managing refugee resettlement (Black, 1990).

The “X” marks in Figure 18(b) indicate the presence of a dependency between the parameters. Keep in mind that the DSM represents ”Provides Information” with columns and ”Requires Information” with rows. Stated differently, data is transferred from the column parameter to the row parameter. In the DSM matrix, all of the ”X” marks above the diagonal are referred to as feedback marks, and they offer necessary inputs that are not currently available. As a result, assumptions will be the foundation for the information inputs from parameters reading down a column of the DSM matrix. Marks of feedback or cycles above the diagonal of the DSM (upper triangular matrix) are undesirable and necessitate lengthy iterations.

To decrease or eliminate the feedback marks in the upper triangle matrix by partitioning, the DSM matrix displayed in Figure 18(b) can be adjusted by concurrently rearranging the rows and columns (Yassine, A.; Braha, D., 2003). Partitioning will enable us to determine which parameters will be carried out in parallel or in series, as well as which ones are coupled and call for iteration in order to ensure the successful management of the resettlement of refugees.

The feedback marks are decreased to 3 (see Figure 19(a)) by applying partitioning in the original DSM displayed in Figure 18(b). The most difficult and time-consuming aspect of this project is the cluster loop of coupled parameters of 2, 3, and 4 cycles, as this figure illustrates (requires iteration).

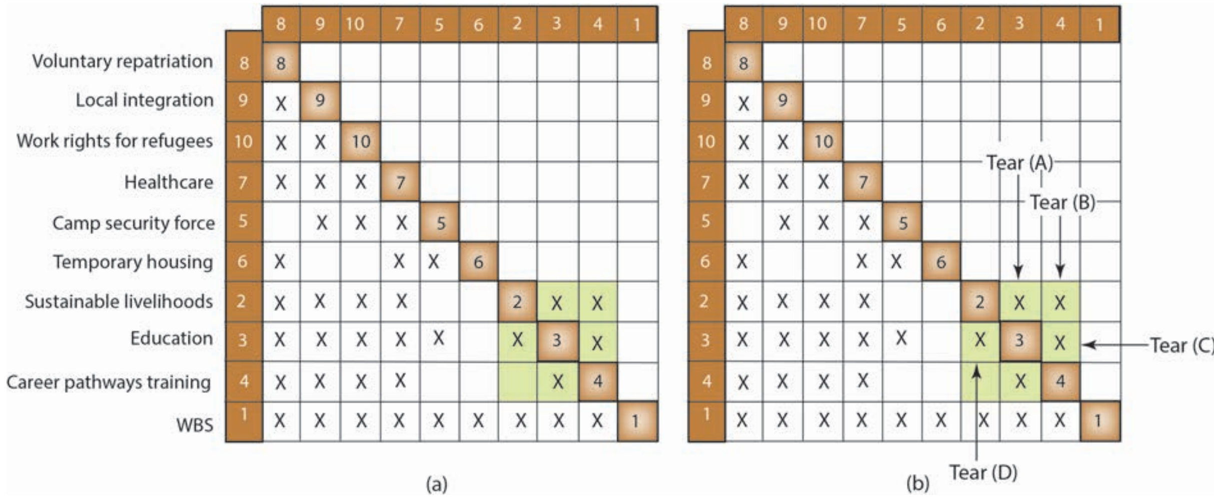


Figure 19: (a) Partitioned DSM, (b) Four cases of tearing.

3.4.1 DSM Tearing

Rearranging coupled tasks within a block to find an initial ordering to begin the iteration process is known as ”tearing” (Kron G., 1963). When coupled tasks are found in a DSM, they move on to the next stage of analysis called DSM tearing, which involves identifying some feedback marks that can be removed from the matrix with the least amount of impact on the process design. Information loss results from tearing, even though it can help reduce the cluster’s complexity and size and expedite the design process. Because of this, it’s important to carefully limit the amount of tears to a manageable amount to avoid relying too heavily on initial estimations.

Figure 20 displays four examples of tearing. In conclusion, compared to other scenarios, the ripped DSM depicted in Figure 20(D) offers a more comprehensive and straightforward parameter modeling framework. The relationship between parameters can be effectively identified with this new DSM. The system’s complexity is significantly reduced because, with the exception of one coupling, all of the relationships between the parameters are either sequential or parallel.

3.4.2 Discussions

There are multiple ways to begin interpreting the intricate nature of the refugee resettlement issue, thanks to the DSM tearing. Every DSM tear suggests ignoring the influence of one parameter on another, if only momentarily.

The impact of parameter 3. Education on parameter 2. Sustainable livelihoods, for instance, is disregarded by Tear (A). The matrix is rearranged after this effect is eliminated to see if a decoupled matrix appears, as seen in Figure 20 (A). Unfortunately, there are still two coupled parameters in this instance: the effect of parameter 3. Education on parameter 4. Career pathways training, as well as the impact of parameter 4. Career pathways training on parameter 2. Sustainable livelihoods.

The goal of the transdisciplinary researchers working on the refugee resettlement issue is to find a means to begin tackling every aspect of the problem. In this instance for Tear (A), the analysis shows that training in career pathways is necessary before creating sustainable livelihoods, but training in career pathways cannot be completed without first supplying education. Thus, it is still an unsolvable issue.

Fortunately, Tear (D) provides a possible way forward. This tear temporarily ignores the effect of parameter 2 Sustainable livelihoods on parameter 3. Education. With this modification, there remains only one coupled element in the matrix after reordering as shown in Figure 20 (D), the effect of parameter 4 Career pathways training on parameter 3 Education. Considering these parameters, a reasonable course of action is suggested. If funding for education is provided–perhaps by an outside aid organization or the government, the refugees can begin Career pathways training to start on their journey to resettlement. The other coupled parameters for Education and Career pathways training indicates that perhaps these factors should be handled together, rather than sequentially. Career pathways training can be provided concurrently with more general education, which makes sense in its real-world implementation since these are both educational activities and would require similar or related facilities, personnel, and skills.

Different approaches can be taken into consideration to turn seemingly intractable problems into ones that are unstuck by closely examining the parameters and coupling in the DSM matrix and asking about the practical effects of tearing. It provides a process for the group to analyze each of their options separately and search for workable solutions that work for a specific circumstance, like this refugee resettlement issue.

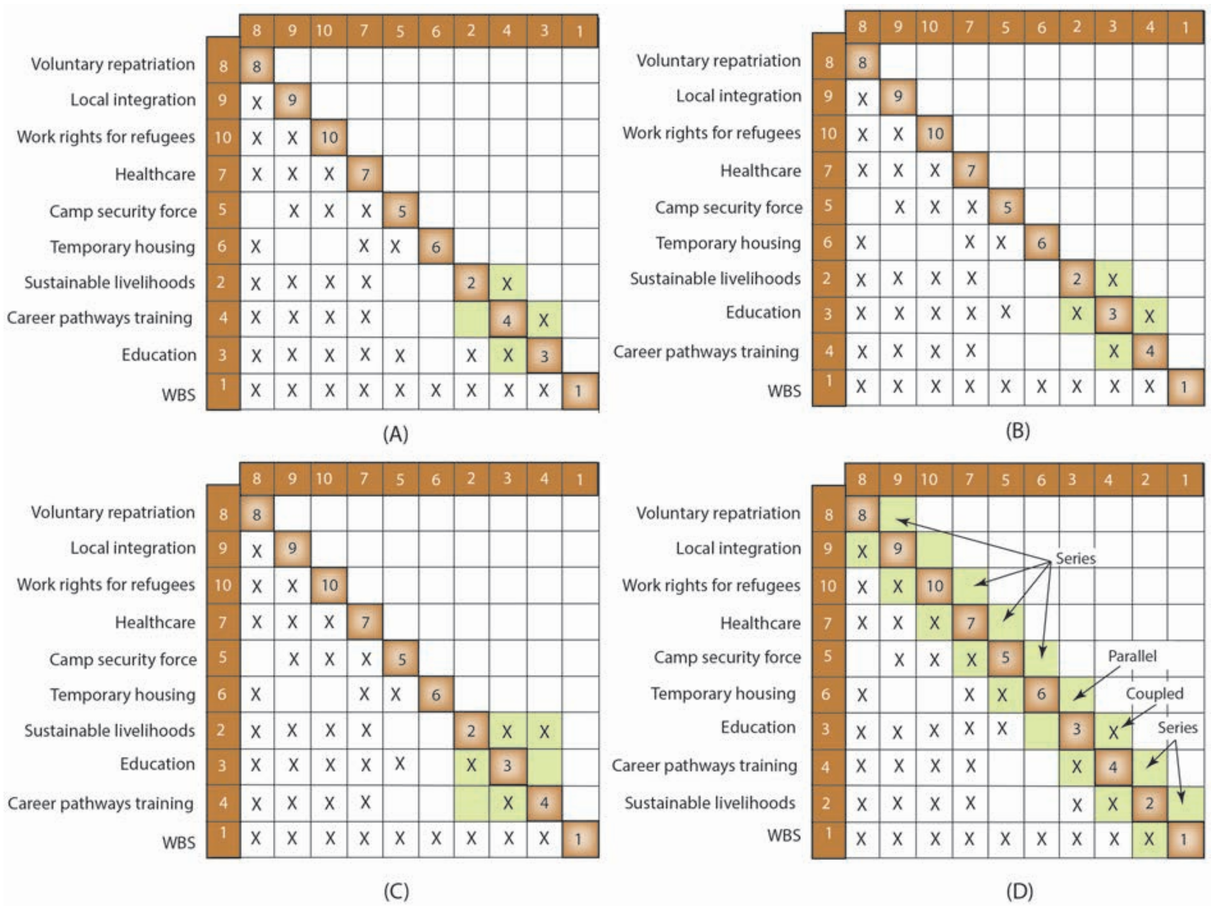


Figure 20: (a) Four cases of DSM tearing.

4 Integrating QFD with Axiomatic Design

According to Tate et al. (2006), axiomatic design (AD) provides scalability for the development of complex systems, general principles for effective decision-making, and discipline-independent representations of a general design process. According to Suh et al. (1978), AD aids in cost reduction, lowers risk associated with product development, and expedites product marketing. The two basic AD axioms listed below provide a logical foundation for assessing the suggested solution options (Suh, 2001).

4.1 Independence Axiom

The *Independence Axiom* ensures that the functional requirements remain independent of one another. That is, each functional requirement must be met by the design parameters that correspond to it, without compromising the satisfaction of the others. Stated differently, a single design parameter fulfills a single functional requirement.

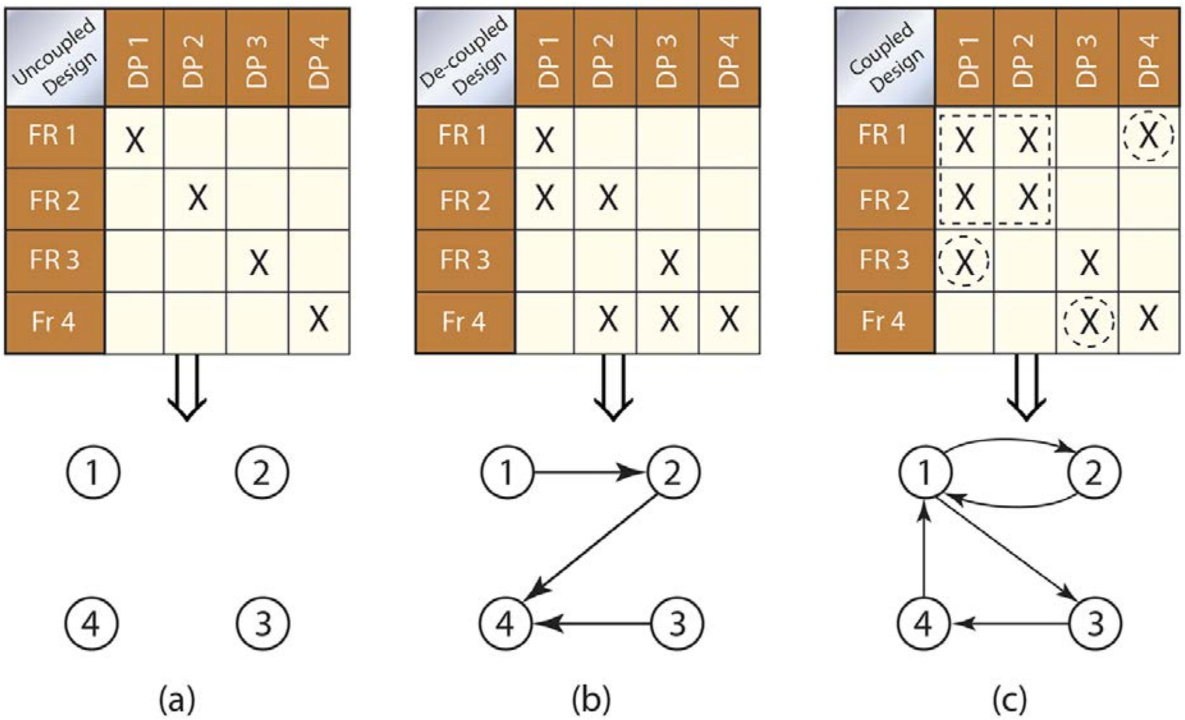


Figure 21: (a) Uncoupled design, (b) De-coupled design, (c) Coupled design.

An uncoupled design is depicted in Figure 21(a), where each functional requirement is satisfied by its corresponding design parameter on its own, without having an impact on the others.

Figure 21(b) illustrates a design that is decoupled (a triangular matrix). FR1 and FR2 are impacted by DP1, and FR4 is impacted by all three of DP2, DP3, and DP4. The triangular matrix implies a sequence in setting the DPs. For the matrix shown, the sequence for setting the design parameters is given in the graph. First DP1 is set. Then DP2 is set, compensating for DP1's effects on FR2 as needed. DP3 is set independently of the others, and finally, DP4 is set to ensure FR4 is satisfied, no matter the effects of DP2, DP3, and DP4.

In Figure 21(c), a coupled design is shown. In this case, there is no optimal sequence for setting the design parameters, only iteration. The relationship between the design parameters and their functional requirements is circular (coupled); DP1 affects FR1 and FR2, and DP2 affects FR1 and FR2 also. This is also a circular relationship between DP1, DP3, and DP4 and their functional requirements as shown in the cycle in the graph.

4.2 Information Content Axiom

Reduces the design's information content. The Independence Axiom must be met before using the Information Axiom to choose the best design from a range of reasonable options. The Information Axiom

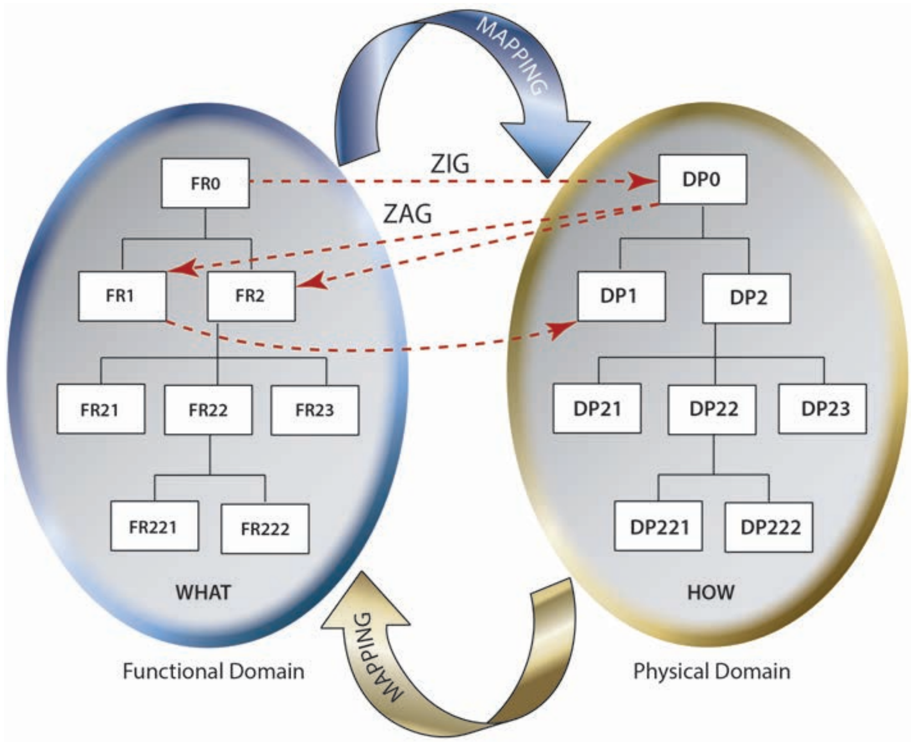


Figure 22: Zigzagging to decompose FRs and DPs (Ertas and Gulbulak, 2021, [22]).

places a strong emphasis on design optimization, providing a solution that minimizes the amount of information contained in the design while fully implementing the functional requirements with the fewest number of components and interfaces.

4.3 Zigzagging and Decomposition

According to AD methodology, the system design process should begin at a high level (abstract) and work its way down to progressively more detailed levels until the system design is sufficiently defined. Every stage of the design process should adhere to the Independence Axiom. The decomposing process is carried out by '*zigzagging*" between FR and DP domains, as seen in Figure 22.

The functional requirement (FR0) for the management of refugee resettlement was determined from Figure 6 and is titled "administration of successful refugee resettlement." The first functional requirement was produced as

[FR1:] Secure physical needs
[FR2:] Meet financial needs
[FR3:] Provide long-term livelihood

The following design parameters (DPs) are selected to fulfill each of the above FRs:

[DP 1:] Physical and social services
[DP 2:] Educational and employment system
[DP 3:] Defined long-term plans

A road map for the levels of decomposition is shown in Figure 23. The decomposition of functional requirements and master matrix are shown in Figures 24 and 25, respectively.

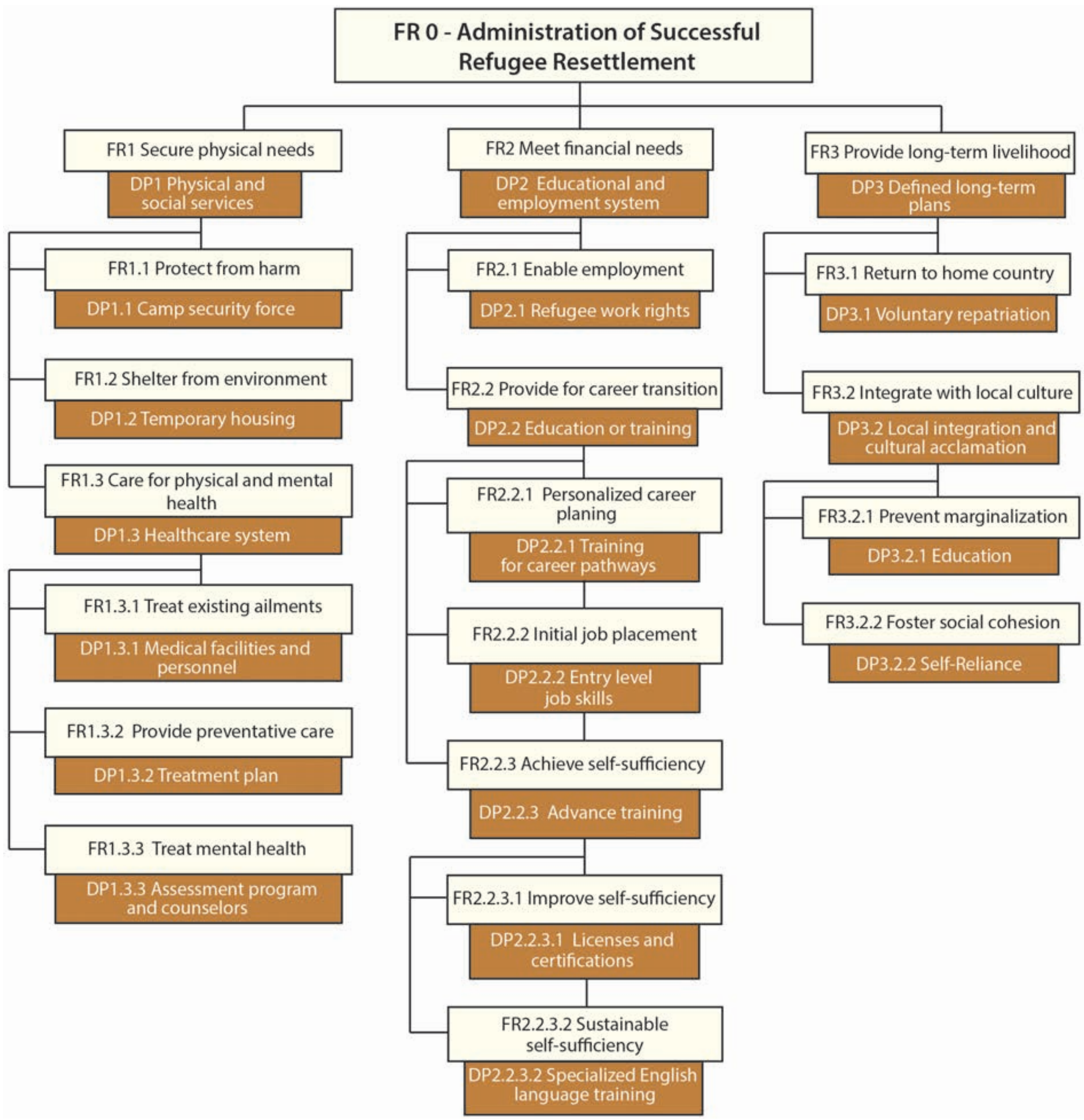


Figure 23: AD high-level design mapping FRs to DPs.

FR1 Secure physical needs	X			DP1 Physical and social services
FR2 Meet financial needs	X	X	X	DP2 Educational and employment system
FR3 Provide long-term livelihood	X	X	X	DP3 Defined long-term plans

FR1 Secure physical needs		DP1.1	DP1.2	DP1.3	DPs ↓
Protect from harm	FR1.1	X	X		Camp security force
Shelter from environment	FR1.2		X		Temporary housing
Care for physical and mental health	FR1.3		X	X	Healthcare system
FR1.3		DP1.3.1	DP1.3.2	DP1.3.3	
Treat existing ailments	FR1.3.1	X	X		Medical facilities and personnel
Provide preventative care	FR1.3.2	X	X		Treatment plan
Treat mental health	FR1.3.3	X		X	Assessment program and counselors
FR2 Meet financial needs		DP2.1	DP2.2		
Enable employment	FR2.1	X			Refugee work rights
Provide for career transition	FR2.2		X		Education or training
FR2.2 Provide for career transition		DP2.2.1	DP2.2.2	DP2.2.3	
Personalized career planing	FR2.2.1	X			Training for career pathways
Initial job placement	FR2.2.2	X	X		Entry level job skills
Achieve self-sufficiency	FR2.2.3	X		X	Advance training
FR2.2.3 Achieve self-sufficiency		DP2.2.3.1	DP2.2.3.2		
Improve self-sufficiency	FR2.2.3.1	X	X		Licenses and certifications
Sustainable self-sufficiency	FR2.2.3.2		X		Specialized English language training
FR3 Provide long-term livelihood		DP3.1	DP3.2		
Return to home country	FR3.1	X	X		Voluntary repatriation
Integrate with local culture	FR3.2	X	X		Local integration and cultural acclamation
FR3.2.1Integrate with local culture		DP3.2.1	DP3.2.2		
Prevent marginalization	FR3.2.1	X	X		Education
Foster social cohesion	FR3.2.2		X		Self-Reliance

Figure 24: Decomposition of FRs.

Design Parameters

Functional Requirements / Numbers	1.1	1.2	1.3	1.3.1	1.3.2	1.3.3	2.1	2.2	2.2.1	2.2.2	2.2.3	2.2.3.1	2.2.3.2	3.1	3.2	3.2.1	3.2.2	
1.1	x	x																FR1
1.2		x																
1.3		x	x															
1.3.1				x	x													
1.3.2				x	x													
1.3.3				x		x												
2.1							x											FR2
2.2								x										
2.2.1									x									
2.2.2									x	x								
2.2.3									x		x							
2.2.3.1												x	x					
2.2.3.2													x					
3.1														x	x			FR3
3.2														x	x			
3.2.1																x	x	
3.2.2																	x	

(a)

Design Parameters

Functional Requirements / Numbers	1.2	1.3	1.1	1.3.1	1.3.2	1.3.3	2.1	2.2	2.2.1	2.2.2	2.2.3	2.2.3.2	2.2.3.1	3.1	3.2	3.2.2	3.2.1
1.2	x																
1.3	x	x															
1.1	x		x														
1.3.1				x	x												
1.3.2				x	x												
1.3.3				x		x											
2.1							x										
2.2								x									
2.2.1									x								
2.2.2									x	x							
2.2.3									x		x						
2.2.3.2												x					
2.2.3.1												x	x				
3.1														x	x		
3.2														x	x		
3.2.2																x	
3.2.1																x	x

(b)

Figure 25: Master matrix.

4.4 Discussions

The master design matrix (see Figure 25) shows the relationship between the lowest-level DPs and FRs. This matrix allows the designer or system architect to ensure that lower-level decisions are consistent with the system architecture at the higher levels of the design and that later design decisions have not introduced new coupling in the design.

The use of axiomatic design in the transdisciplinary framework of integrated TD tools, as shown in Figure 2, can fulfill two roles. First, axiomatic design can be used to analyze an existing design (or proposed design concept) to identify coupling and work together with tools from TRIZ to find solutions that eliminate contradictions. The is the arrow on the right-hand side of Figure 2. On the other hand, once a solution is proposed without contradictions or coupling, axiomatic design can be used to detail the design from an abstract concept to a detailed level in which the designer "knows what to do from there."

A couple of points illustrate how axiomatic design complements the other integrated TD tools. First, by representing the design in terms of both functional requirements (FRs) and design parameters (DPs), this focuses the team on fulfilling the verbs of the FRs which provides a link between the stakeholders and the system design. Second, the zigzag process provides opportunities for the team to consider alternative solutions at either the higher, abstract level or the detailed, concrete level, and it makes explicit aspects of the design that will change depending on the selected DP. Third, the decomposition of each FR-DP pair into its children prompts the team to identify explicitly the necessary and sufficient conditions for fulfilling that FR. Finally, if the design matrix is decoupled, following the Independence Axiom, then the master design matrix provides a roadmap for the implementation of the system.

As seen in Figure 25(a), there are only two instances of coupling and a small number of off-diagonal elements (which are moved to a lower triangle by partitioning; see Figure 25(b)). Those design parameters can be implemented in parallel with the others due to the uncoupled relationships among them. However, elements DPs 1.3.1 and 1.3.2 (Medical facilities and personnel and Treatment plan) are coupled with FRs 1.3.1 and 1.3.2 Treat existing ailments and Provide preventative care), and elements DP 3.1 and 3.2 (Voluntary repatriation and Local integration and cultural acclamation) are coupled with FRs 3.1 and 3.2 (Return to home country and Integrate with local culture).

The coupling between the first two elements can be reduced or eliminated through TRIZ principles such as separation in time or separation in space. In particular, the medical personnel involved in treating the refugees could determine the correct sequence and facilities for the refugees to meet their needs in a particular case. There is probably not a general solution, but instead, an individualized treatment plan that could satisfy both requirements. Likewise, it will be up to the refugees themselves to decide whether to repatriate or integrate into the local community, given the constraints of the current international situation. Fortunately, as can be seen in the matrix, this decision is well downstream of most of the needs of the refugees. Their situation can be stabilized and improved to prepare them for either option.

5 Final Remarks

This paper's primary goal is to present a TD-integrated tool application for managing refugee resettlement. By taking into account the primary parameters influencing the difficult problems in the administration of refugee resettlement, the parameters utilized in this study are made simpler.

Interpretive Structural Modeling, a methodology for dealing with complex design and development, is one of the key TD tool components of this research. Developing collective intelligence to comprehend the relationships between defined TD solutions and the management of refugee resettlement is a crucial component of interpretive structural modeling.

The digraph for managing refugee resettlement, as illustrated in Figure 16, was created using the reachability matrix as outlined in the ISM approach. The direct and indirect relationships between the TD solutions influencing the effectiveness of the management of refugee resettlement are graphically represented in this figure.

Level VI is the most complex level due to its numerous interactions with the other levels, as seen in Figure 16. The four primary TD solutions–"*sustainable livelihoods* (measure 2), "*education* (measure 3), "*career pathways training* (measure 4), and "*temporary housing* measure (6)—are crucial and must be examined before other factors because they influence other factors at a higher level. Figure 16 illustrates these measures. Since TD solution 1 (WBS) only contains outgoing paths, it is the source element. The management of refugee resettlement is represented by the linear mapping found in TD solutions 5, 7, 10, 9, and 8.

The *Cyclomatic Complexity Measure* (McCabe, 1976) can be used to calculate the complexity of the MRR using the digraph presented in Figure 16. The cyclomatic complexity, M, is computed mathematically by

$$M = E - N + 2P$$

where
E = the number of edges of the graph (E=15)
N = the number of nodes of the graph (N=10)
P = the number of connected components (P=1)

$$M = 15 - 10 + 2(1) = 7$$

The complexity of an issue is difficult to understand when the cyclomatic complexity number is high. The threshold limit value of cyclomatic complexity was suggested by McCabe – "the particular upper bound that has been used for cyclomatic complexity is 10– if the M value is 10 or higher, the issue is said to be complex". We may conclude that the management of refugee resettlement. represented by Figure 16 is not considered complex, however, it is complicated to manage.

The MICMAC chart, as illustrated in Figure 17, offers valuable insights into the relative significance and interdependencies among TD solutions that impact the efficacy of refugee resettlement management. This figure divides all TD solution performance metrics that impact managing the success of refugee resettlement into four groups. Since the autonomous factors in Cluster I have little dependence and little driving force, they will be given less weight when managing the resettlement of refugees. As of this writing, no independent factor has been found for this case. This suggests that every parameter involved in the administration of refugee resettlement is interconnected.

Cluster II comprises dependent parameters with high dependence and low driving power, as shown in Figure 17. Five TD solutions are included in Cluster II, as shown in this figure: measure *camp security force,* (5); measure *healthcare,* (7); measure *work rights for refugees,* (10); measure *local integration,* (9); and measure *voluntary repatriation),* (8). While these TD solutions might not have an impact on other parameters, they are impacted by other TD solutions that have an impact on the management of the resettlement process for refugees. As demonstrated in Figure 16, these variables are linearly related to one another in order to fulfill the management process's necessary goal.

Linkage TD solutions in cluster III have high driving and high dependence power. Cluster III's parameters are unstable because they interact with one another; any changes made to them will impact other parameters as well as provide feedback for the original parameters. There are no unstable TD solutions in this design that could negatively impact the management process, as shown in Figure 17.

Cluster IV comprises five independent parameters with strong driving power but very weak dependence: *WBS,* measure (1); *sustainable livelihoods,* measure (2); *education,* measure (3); *career pathways training,* measure (4); and *temporary housing,* measure (6). The *Work Breakdown Structure (WBS)* is at the bottom of the digraph and has strong driving power, dictating the refugee settlement management process, as Figure 16 illustrates. Resettlement activities must be carefully planned, carried out with efficiency, and transparently using WBS.

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References

Black, T. A. (1990). *A Systems Design Methodology Applied to Automotive Brake Design.* MIT Masters Thesis.

Delbecq, A. L.; VandeVen, A. H. (1971). A Group Process Model for Problem Identification and Program Planning. *Journal of Applied Behavioral Science.* 7, pp. 466–91. doi:10.1177/002188637100700404

Duperrin, J.C. and Godet, M. (1973) Methode De Hierar Chization des Elements D'um System, Rapport Economique de CEA, pp.45–51.

Eppinger S.D. and Browning, T.R. (2012). *Design structure matrix methods and applications.* MIT Press.

Ertas, A., Gulbulak, U., (2021). *Managing System Complexity through Integrated Transdisciplinary Design Tools.* ATLAS Publishing, 2021 (link: https://www.rb-tdinstitute.org/index.php/td-books-reports), ISBN: 978-0-9998733-1-1; doi:10.22545/2021b/B1.

Halpern, P., (2008). Refugee economic self-sufficiency: an exploratory study of approaches used in the office of refugee resettlement programs. https://aspe.hhs.gov/system/files/pdf/75561/report.pdf (accessed March 1,2020).

Harary, F.; Norman, R. V.; and Cartwright, D. (1965). *Structural Models: An Introduction to the Theory of Directed Graphs*, Willey, New York.

Kirsten Schuettler, (2017). Refugees' right to work: Necessary but insufficient for formal employment of refugees. World Bank, November 09, 2017. Accessed October 9, 2022.

Kron G. (1963). *'Diakoptics', piecewise solution of large scale systems of equations.* Ph.D. Thesis, University of Texas, Austin.

Mann, D. (2004). Comparing The Classical and New Contradiction Matrix - Part 1 - Zooming Out. Retrieved 08 25, 2020, from The TRIZ Journal: https://triz-journal.com/comparing-classical-new-contradiction-matrix-part-1-zooming

McCabe, T. J. (1976). Describing Cyclomatic Complexity. *IEEE Transactions on Software Engineering,* Vol. 2, No. 4, p. 308.

Moran, D., Gulbulak, U., Ertas, A., Yancey, S., Cody, C., Puente, K., Zinsmeyer, J., Agbontaen , I., Alejandra, C., Bakir, A. H., Baucum , H., Daniel, M. E., Gabriel, R., Heriberto, M., Kodwo, T., Lopez, E. G., Melendez, O., Nicholas, E., Rippert, J., Yadav, S., Watts, R., Yunseon, K., Zatloka, M. (2020). Complexity of Global Refugee Crisis: Needs for Global Transdisciplinary Collaboration, *Transdisciplinary Journal of Engineering & Science*, Vol. 11, pp. 115-131.

Moran, D., Ertas, A., Gulbulak, U. (2021). A Unique Transdisciplinary Engineering-Based Integrated Approach for the Design of Temporary Refugee Housing Using Kano, HOQ/QFD, TRIZ, AD, ISM and DSM Tools. *Designs,* 5(2), 31; https://doi.org/10.3390/designs5020031.

Naveiroa, R. M., Oliveira, V. M., (2018). QFD and TRIZ integration in product development: a Model for Systematic Optimization of Engineering Requirements. Production, Vol. 28.

Project Management Practices 1 Work Breakdown Structure (Rev E, June 2003, p.1), https://www4.rcf.bnl.gov/videbaks/hft/cd1/DOE_guidance_wBS.pdf

Steward, D.V. (1981). *Systems Analysis and Management: Structure. Strategy, and Design.* Petrocelli/McGraw-Hill, New York.

Suh, P.; Bell, A. C. and Gossard, D. C. (1978). On an Axiomatic Approach to Manufacturing and Manufacturing Systems. *Journal of Engineering for Industry,* Vol. 100, pp. 127-130.

Suh, N. P. (2001). *Axiomatic Design: Advances and Applications,* New York: Oxford University Press.

Tate, D.; Ertas, A., Tanik, M. and Maxwell, T.T. (2006). *A TD Framework for Engineering Systems Research and Education based on Design and Process,* ATLAS TD Modules, www.theatlas.org.

Terninko, J., Zussman, A., & Zlotin, B. (1998). *Systematic innovation: an introduction to TRIZ.* Boca Raton: CRC Press.

Tursch, P., Christine Goldmann, Ralf Woll, (2015). Integration of TRIZ into QFD. *Management and Production Engineering Review*, Vol. 6, No. 2, pp. 56–62.

Warfield, J. 1974. *Structuring Complex Systems.* Battelle Memorial Institute, Columbus, OH, Battelle Monograph, No.

Yamashina H., T. Ito and H. Kawada, (2002). Innovative product development process by integrating QFD and TRIZ. *International Journal of Production Research*, vol. 40, no. 5, pp.1031-1050.

Yassine, A., Braha, D. (2003). Complex Concurrent Engineering and the Design Structure Matrix Method, Concurrent Engineering, *Research and Applications,'*, Volume 11 Number 3, pp. 165-176, 2003.

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Appendix A

Table A1: TRIZ Contradiction Matrix (Engineering Characteristics).

Improving Feature ↓ / Worsening Feature →		Reliability 27	Accuracy of measurement 28	Accuracy of manufacturing 29	Harmful factor acting on object 30	Harmful side-effects 31	Manufacturibility 32	Convenience of use 33	Repairability 34	Adaptability 35	Complexity of device 36	Complexity of control 37	Level of automation 38	Productivity 39
21	Power	19,24 26,31	32,15 2	32,2	19,22 31,2	2,35 18	26,10 34	26,35 18	35,2 10,34	19,17 34	20,19 30,34	19,35 16	28,2 17	28,35 34
22	Waste of energy	11,10 35	32		21,22 35,2	21,35 2,22		35,32 1	2,19		7,23	35,3 15,23	2	28,10 29,35
23	Waste of substance	10,29 39,35	16,34 31,28	35,10 24,31	33,22 30,40	10,1 34,29	15,34 33	32,28 2,24	2,35 34,27	15,10 2	35,10 28,24	35,18 10,13	35,10 18	28,35 10,23
24	Loss of information	10,28 23			22,10 1	10,21 22	32	27,22				35,33	35	13,23 15
25	Waste of time	10,30 4	24,34 28,32	24,26 28,18	35,18 34	35,22 18,39	35,28 34,4	4,28 10,34	32,1 10	35,28	6,29	18,28 32,10	24,28 35,30	
26	Amount of substance	18,3 28,40	13,2 28	33,30	35,33 29,31	3,35 40,39	29,1 35,27	35,29 25,10	2,32 10,25	15,3 29	3,13 27,10	3,27 29,18	8,35	13,29 3,27
27	Reliability		32,3 11,23	11,32 1	27,35 2,40	35,2 40,26		27,17 40	1,11	13,25 8,24	13,35 1	27,40 28	11,13 27	1,35 29,38
28	Accuracy of measurement	5,11 1,23			28,24 22,26	3,33 39,10	6,35 25,18	1,13 17,34	1,32 13,11	13,35 2	27,35 10,34	26,24 32,28	28,2 10,34	10,34 28,32
29	Accuracy of manufacturing	11,32 1			26,28 10,36	4,17 34,26		1,32 35,23	25,10		26,2 18		26,28 18,23	10,18 32,39
30	Harmful factors acting on object	27,24 2,40	28,33 23,26	26,28 10,18			24,35 2	2,25 28,39	35,10 2	35,11 22,31	22,19 29,40	22,19 29,40	33,3 34	22,35 13,24
31	Harmful side-effects	24,2 40,39	3,33 26	4,17 34,26							19,1 31	2,21 27,1	2	22,35 18,39
32	Manufacturability		1,35 12,18		24,2			2,5 13,16	35,1 11,9	2,13 15	27,26 1	6,28 11,1	8,28 1	35,1 10,28
33	Convenience of use	17,27 8,40	25,13 2,34	1,32 35,23	2,25 28,39		2,5 12		12,26 1,32	15,34 1,16	32,26 12,17		1,34 12,3	15,1 28
34	Repairability	11,10 1,16	10,2 13	25,10	35,10 2,16		1,35 11,10	1,12 26,15		7,1 4,16	35,1 13,11		34,35 7,13	1,32 10
35	Adaptability	35,13 8,24	35,5 1,10		35,11 32,31		1,13 31	15,34 1,16	1,16 7,4		15,29 37,28	1	27,34 35	35,28 6,37
36	Complexity of device	13,35 1	2,26 10,34	26,24 32	22,19 29,40	19,1	27,26 1,13	27,9 26,24	1,13	29,15 28,37		15,10 37,28	15,1 24	12,17 28
37	Complexity of control	27,40 28,8	26,24 32,38		22,19 29,28	2,21	5,28 11,29	2,5	12,26	1,15	15,10 37,28		34,21	35,18
38	Level of automation	11,27 32	28,26 10,34	28,26 18,23	2,33	2	1,26 13	1,12 34,3	1,35 13	27,4 1,35	15,24 10	34,27 25		5,12 35,26
39	Productivity	1,35 10,38	1,10 34,28	18,10 32,1	22,35 13,24	35,22 18,39	35,28 2,24	1,28 7,10	1,32 10,25	1,35 28,37	12,17 28,24	35,18 27,2	5,12 27,2	

Table A2: TRIZ–40 Principles.

Principles	**Principles**
1. Segmentation	21. Rushing through
2. Extraction (taking out)	22. Convert harm into benefit
3. Local Quality	23. Feedback
4. Asymmetry	24. Mediator (intermediary)
5. Combination (merging)	25. Self-service
6. Universality	26. Copying
7. Nesting	27. Inexpensive short life
8. Counterweight (anti-weight)	28. Replacement of a mechanical system
9. Prior Counteraction	29. Use pneumatic or hydraulic systems
10. Prior Action	30. Flexible film or thin membranes
11. Cushion in Advance	31. Use of porous materials
12. Equipotentiality	32. Changing the colour
13. Inversion (the other way round)	33. Homogeneity
14. Spheroidality- Curvature	34. Rejecting and regenerating parts
15. Dynamicity	35. Parameter Change
16. Partial, overdone or excessive action	36. Phase transition
17. Moving to a new dimension	37. Thermal expansion
18. Mechanical vibration	38. Use strong oxidisers
19. Periodic action	39. Inert environment
20. Continuity of useful action	40. Composite materials

Source of Table 3.8: Altshuller G. 40 Principles: TRIZ Keys to Technical Innovation. Technical Innovation Center; 2001.