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VALUE-BASED AXIOMATIC DECOMPOSITION (PART II): CASE STUDY

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ABSTRACT

In the second part of this paper, the step-by-step application of the value-based axiomatic decomposition method, proposed in the previous part, is illustrated. The main results are also presented and discussed. The practical application took place at a Portuguese transportation delivery service company. The two main goals for this case study were to assist managers in their decisions during the redesign of the company's delivery service, and to test the applicability of the value-based decomposition method. The context of the case study is firstly explained, followed by the step-by-step application of the proposed decomposition method, and by the discussion of the results obtained.

Keywords: design decomposition, consistency, Axiomatic Design, Functional Analysis System Technique (FAST).

1 INTRODUCTION

The top management of a Portuguese transportation delivery service company, under the scope of company's continual improvement process, decided to start a project to redesign its service process. Axiomatic Design Theory, in particular the proposed value-based axiomatic decomposition method, was employed with the aim of contributing to the redesign effort by providing a logical framework for decision-making.

The application of the proposed decomposition method, described in detail in section 3 of part I of this paper, to this case was a good opportunity to test it in a practical environment in order to determine whether it could be useful in maintaining the coherence of the design decision along all the levels of the detail in the hierarchy.

In addition, the minimization of coupling situations was useful for the company's operational efficiency goals, since the presence of coupling in the service design would greatly increase the chance of rework to occur during the required service planning activities, particularly for non-standard delivery services and time critical delivery services.

2 CASE STUDY

The practical application of the value-based axiomatic decomposition method herein presented was developed to redesign a transportation delivery service provided by a Portuguese company.

2.1 PRE-DECOMPOSITION ACTIVITIES

Knowing the scope of the design project enabled the design team to formulate FR_0 and DP_0:

FR_0 = Transport packages or parcels from one point of location to another, correctly and on-time.
DP_0 = Transportation delivery service.

Through retroactive sources of data (key performance indicators, customer complaints, service reports, among others), individual customer interviews, focus groups and questionnaires, it was possible to gather the raw "voice of the customer" (VOC), which was then converted into more objective customer needs. After eliminating duplications and redundancies, the design team determined the definitive set of customer needs (CNs), which were organised using an affinity diagram [Mizuno, 1988]. The House of Quality framework was then used to translate these CNs into design requirements (DRs), to study the existing relationships between CNs and DRs, and to prioritise the most relevant DRs.

Three basic functions of the transportation delivery service (DP_0) were identified and led the design team to define three initial functional requirements (FR_1, FR_2, and FR_3). The basic function is the required reason for the existence of the service, and answers the question: "what must it do?" [Bytheway, 2007]. A fourth FR (FR_4) that is associated with a secondary function was also defined. The initial set of FRs was then composed as follows:

FR_1 = Deliver all shipped items in good conditions.
FR_2 = Pick and deliver each package/parcel at the correct locations.
FR_3 = Deliver within the required time.
FR_4 = Provide good customer support service.

Please notice that these four FRs are all of the same importance. The main objective in classifying their associated functions as basic or as secondary is to determine which FRs should be decomposed further. As described in section 3.2, sub-FRs should only be developed for the top-level FRs that are associated with a basic function.

The top-level Cs were then specified, classified and their impact on the initial FRs assessed (Table 1). The initial set of FRs and the top-level Cs were validated after analysing if they were actually representative of the CNs and DRs.

With the intent of independently satisfying each of the initial FRs, while meeting the applicable Cs, the design team came up with alternative design solutions. The chosen set of design parameters (DPs) was the following:

DP_1 = Handling, packaging and storage solutions.
DP_2 = Description and location information about the specific places for pickup and delivery.
DP_3 = Delivery speed.
DP_4 = Customer Service & Support system.

The design matrix relating the initial sets of FRs and DPs, representing the design intent, showed a decoupled design:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 \\ 0 & X & 0 & 0 \\ X & X & X & 0 \\ X & X & X & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \end{Bmatrix} \qquad (1)$$

2.2 DECOMPOSITION ACTIVITIES

The three FR-DP pairs associated with basic functions were decomposed, while the FR_4-DP_4 pair (associated with a secondary function) was not. The decomposition sequence followed the order indicated in the design matrix of equation 1.

2.2.1 DECOMPOSITION OF THE FR_1-DP_1 PAIR

To develop a necessary and sufficient number of sub-FRs, all potential sources for identifying sub-FRs were considered, namely the following: DP_1, FR_1, top-level Cs, DM of equation 1, and the set of CNs. The sources that lead to the definition of the following sub-FRs are described in Table 2:

$FR_{1.1}$ = Handle transported items properly and with care.
$FR_{1.2}$ = Store shipped items properly during carriage.
$FR_{1.3}$ = Protect each shipped item from damage.
$FR_{1.4}$ = Prevent each shipped item from loss during service operations.
$FR_{1.5}$ = Provide information to customer about the current location of his/her shipped items.

Table 2. Sub-FRs resulted from the decomposition of the FR_1-DP_1 pair, their sources and associated functions.

Functional requirement	Associated function	Source(s)
$FR_{1.1}$	Dependent	DP_1, FR_1
$FR_{1.2}$	Dependent	DP_1, FR_1
$FR_{1.3}$	Dependent	DP_1, FR_1
$FR_{1.4}$	Dependent	FR_1
$FR_{1.5}$	Support	C-6

All these sub-FRs have the same importance, despite the classification of their corresponding functions. The sub-FRs that can answer "how" the FR_1 is performed were classified as dependent functions, so they were further detailed through decomposition. On the opposite, the sub-FRs not answering this question were classified as support functions, so they were considered to be at the leaf-level.

Table 1. Description of the top-level Cs, their classification and impact on FRs.

Constraints		Impact of FRs			
Code	***Description***	**FR_1**	**FR_2**	**FR_3**	**FR_4**
	Critical performance specifications				
C-1	On-time delivery for next-day services			X	
C-2	On-time-delivery for same-day services			X	
C-3	On-time pickup for next-day services			X	
C-4	On-time pickup for same-day services			X	
	Interface constraints				
C-5	Ensure courtesy and politness when interacting with the customer		X		X
C-6	Enable customer interaction during the whole service	X			X
C-7	Adequate the vehicles used to the type of items to be transported	X	X		
C-8	Optimise load fulfilment of the vehicles	X			
	Global constraints				
C-9	Comply with the organisation's quality, safety and environmental	X	X	X	X
C-10	Comply with all applicable legal and standrad requirements	X	X	X	X
C-11	Provide trace-and-track solutions in all services	X	X	X	X
	Project constraints				
C-11	Integrate maximum of well-proven design solutions	X	X	X	X
C-12	Reuse maximum of existing design solution	X	X	X	X
	Feature constraints				
	N/A				

The Cs applicable to this level of the hierarchy, regarding the FR_1-DP_1 branch, resulted from the refinement of the top-level Cs, indicated in Table 1.

Before being mapped to the physical domain, the five sub-FRs (from $FR_{1.1}$ to $FR_{1.5}$) were checked for consistency to the parent level. The results are presented in Figure 1.

The decomposed set of sub-FRs was then mapped to the physical domain to define the corresponding set of sub-DPs:

$DP_{1.1}$ = Handling procedures.
$DP_{1.2}$ = Storage and packing conditions.
$DP_{1.3}$ = System of packages.
$DP_{1.4}$ = Shipment labelling and documentation system.
$DP_{1.5}$ = Track and trace service.

The design matrix for the second level of the hierarchy, for this branch, complied with the Independence Axiom:

$$\begin{Bmatrix} FR_{1.1} \\ FR_{1.2} \\ FR_{1.3} \\ FR_{1.4} \\ FR_{1.5} \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 \\ X & X & 0 & 0 & 0 \\ X & X & X & 0 & 0 \\ 0 & 0 & 0 & X & 0 \\ 0 & 0 & 0 & X & X \end{bmatrix} \begin{Bmatrix} DP_{1.1} \\ DP_{1.2} \\ DP_{1.3} \\ DP_{1.4} \\ DP_{1.5} \end{Bmatrix} \qquad (2)$$

The consistency of the design matrix elements, to the parent level, was then checked using a full design matrix for this point of the decomposition (Figure 2).

The second level FR-DP pairs that are associated with a dependent function were further decomposed, until their parent level FR_1-DP_1 pair could be fully implemented. The same reasoning of the value-based axiomatic decomposition method, previously described, was applied. The results of the decomposition for the branch corresponding to the FR_1-DP_1 can be regarded in Figure 3.

		DP1							
		DP1.1	DP1.2	DP1.3	DP1.4	DP1.5	DP2	DP3	DP4
FR1	FR1.1	X	0	0	0	0	0	0	0
	FR1.2	X	X	0	0	0	0	0	0
	FR1.3	X	X	X	0	0	0	0	0
	FR1.4	0	0	0	X	0	0	0	0
	FR1.5	0	0	X	X	X	0	0	0
FR2		0	0	0	0	0	X	0	0
FR3		0	0	0	0	0	0	X	0
FR4		0	0	0	0	0	0	0	X

Figure 2. Full design matrix for the second level of the decomposition of the FR_1-DP_1 pair.

2.2.2 DECOMPOSITION OF THE FR_2-DP_2 AND FR_3-DP_3 PAIRS

Since there is no penalty for decomposing one branch of the design hierarchy more deeply than another, provided that the order follows that given in the design matrix of equation 1, the FR_1-DP_1 node was decomposed first. Attending to this guideline, the FR_2-DP_2 pair was then decomposed, followed by the decomposition of the FR_3-DP_3 pair.

Again, the iterative process of the value-based decomposition method, described in Figure 4 of part I of this paper, was used to consistently deploy, layer by layer of the hierarchy, the design decisions, in terms of sub-FRs, sub-DPs, elements of the DM, and refinement of Cs, of the high-level FR_2-DP_2 and FR_3-DP_3 pairs.

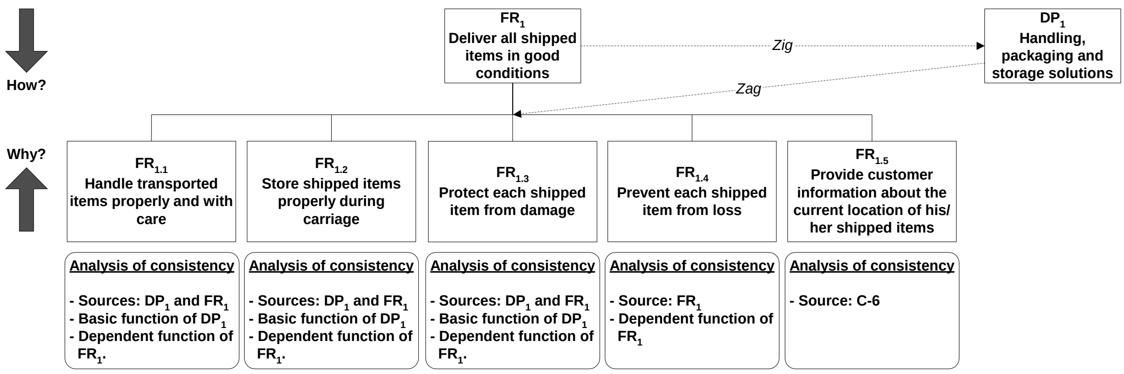

Figure 1. Checking of the consistency of the sub-FRs resulted from the decomposition of the FR_1-DP_1 pair.

FR$_0$: Transport packages or parcels from one point of location to another, correctly and on-time	Overall function
FR$_1$: Deliver all shipped items in good conditions	Basic function
FR$_{1.1}$: Handle transported items properly and with care	Dependent function
FR$_{1.1.1}$: Handle with care during moving operations	Dependent function
FR$_{1.1.2}$: Handle with care during loading operations	Dependent function
FR$_{1.1.3}$: Handle with care during unloading operations	Dependent function
FR$_{1.1.4}$: Warn operators for special handling items	Support function
FR$_{1.2}$: Store shipped items properly during carriage	Dependent function
FR$_{1.2.1}$: Protect shipped items from physical damage in the cargo area of the vehicle	Dependent function
FR$_{1.2.2}$: Prevent shipped items from sliding and moving during carriage	Dependent function
FR$_{1.2.3}$: Preserve the non-physical critical properties of the shipped items during carriage	Dependent function
FR$_{1.2.4}$: Maximise the available space of the cargo	Support function
FR$_{1.3}$: Protect each shipped item from damage	Dependent function
FR$_{1.3.1}$: Maintain the physical integrity of the packaged items	Dependent function
FR$_{1.3.2}$: Preserve the non-physical critical properties of the packaged items	Dependent function
FR$_{1.3.3}$: Ensure the packaging for each item is correctly done	Support function
FR$_{1.4}$: Protect each shipped item from loss during service operations	Dependent function
FR$_{1.5}$: Provide information to customer about the current location of his/her shipped items	Support function
FR$_2$: Pick and deliver each package/parcel at the correct locations	Basic function
FR$_{2.1}$: Pick and ship at the right location address	Dependent function
FR$_{2.1.1}$: Contact with the consignor whenever needed	Support function
FR$_{2.1.2}$: Ensure all parcels are picked up at the address required by the consignor	Dependent function
FR$_{2.1.3}$: Provide geographical location of the pickup address to the courier driver	Support function
FR$_{2.2}$: Deliver each shipped package/parcel at the required location address	Dependent function
FR$_{2.2.1}$: Contact with the consignee whenever needed	Support function
FR$_{2.2.2}$: Ensure all parcels are delivered at the consignee's address	Dependent function
FR$_{2.2.3}$: Provide geographical location of the delivery address to the courier driver	Support function
FR$_{2.3}$: Notify customer about the delivery status	Support function
FR$_3$: Deliver within the required time	Basic function
FR$_{3.1}$: Pickup package/parcel at the agreed time	Dependent function
FR$_{3.1.1}$: Schedule the pickup service for the defined pickup time	Dependent function
FR$_{3.1.2}$: Update service status in the trace & tracking system	Support function
FR$_{3.1.3}$: Inform consignor about the pickup status	Support function
FR$_{3.2}$: Deliver shipped package/parcel at the required time	Dependent function
FR$_{3.2.1}$: Schedule the delivery service for the defined transit time	Dependent function
FR$_{3.2.2}$: Update service status in the trace & tracking system	Support function
FR$_{3.2.3}$: Inform consignor about the delivery status	Support function
FR$_{3.3}$: Comply with the optional delivery procedures requested by the customer	Support function
FR$_4$: Provide good customer support service	Secondary function

- DP$_0$: Transportation delivery service
  - DP$_1$: Handling, packaging and storage solutions
    - DP$_{1.1}$: Handling procedures
      - DP$_{1.1.1}$: Handling procedures during moving activities, for both normal and special handling items
      - DP$_{1.1.2}$: Handling procedures during loading activities, for both normal and special handling items
      - DP$_{1.1.3}$: Handling procedures during unloading activities, for both normal and special handling items
      - DP$_{1.1.4}$: Custom labels for special handling items
    - DP$_{1.2}$: Storage and packing conditions
      - DP$_{1.2.1}$: Procedures for the immobilisation of the shipped items placed in the cargo area
      - DP$_{1.2.2}$: Procedures for the physical protection of the shipped items placed in the cargo area
      - DP$_{1.2.3}$: Cargo environmental controlled and customised conditions
      - DP$_{1.2.4}$: Load optimisation procedure
    - DP$_{1.3}$: System of packages
      - DP$_{1.3.1}$: Protection features incorporated in the package, customised to the type of good to be transported
      - DP$_{1.3.2}$: Preservation features inherent to the package, customised to the type of good to be transported
      - DP$_{1.3.3}$: Packaging instructions
    - DP$_{1.4}$: Shipment labelling and documentation system
    - DP$_{1.5}$: Track and trace service
  - DP$_2$: Description and location information about the specific places for pickup and delivery
    - DP$_{2.1}$: Full address of the consignor
      - DP$_{2.1.1}$: Name and contact of the consignor
      - DP$_{2.1.2}$: Address description in the pickup order
      - DP$_{2.1.3}$: Map coordinate finder – location for pickup
    - DP$_{2.2}$: Full address of the consignee
      - DP$_{2.2.1}$: Name and contact of the consignee
      - DP$_{2.2.2}$: Description of the address for delivery in the waybill and package(s)
      - DP$_{2.2.3}$: Map coordinate finder – location for delivery
    - DP$_{2.3}$: Customer notification system
  - DP$_3$: Delivery speed
    - DP$_{3.1}$: Service pickup time
      - DP$_{3.1.1}$: Most suitable network route to comply with the defined pickup time
      - DP$_{3.1.2}$: Track and trace update system – Pickup
      - DP$_{3.1.3}$: Online customer service – pickup status
    - DP$_{3.2}$: Transit time for the service
      - DP$_{3.2.1}$: Most suitable network route to comply with the required transit time
      - DP$_{3.2.2}$: Track and trace update system – Delivery
      - DP$_{3.2.3}$: Online customer service – delivery status
    - DP$_{3.3}$: Custom delivery instructions in the waybill
  - DP$_4$: Customer Service & Support system

Figure 3. Overview of the decomposition results for the redesign of the transportation delivery service.

	DP1													DP2							DP3							DP4
	DP1.1				DP1.2				DP1.3			DP1.4	DP1.5	DP2.1			DP2.2			DP2.3	DP3.1			DP3.2			DP3.3	
	DP1.1.1	DP1.1.2	DP1.1.3	DP1.1.4	DP1.2.1	DP1.2.2	DP1.2.3	DP1.2.4	DP1.3.1	DP1.3.2	DP1.3.3			DP2.1.1	DP2.1.2	DP2.1.3	DP2.2.1	DP2.2.3	DP2.2.4		DP3.1.1	DP3.1.2	DP3.1.3	DP3.2.1	DP3.2.2	DP3.2.3		
FR1 / FR1.1 / FR1.1.1	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR1.1.2	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR1.1.3	X	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR1.1.4	X	X	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR1.2 / FR1.2.1	0	X	X	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR1.2.2	0	X	0	0	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR1.2.3	0	X	0	0	X	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR1.2.4	0	0	0	0	X	X	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR1.3 / FR1.3.1	X	X	X	0	X	X	0	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR1.3.2	X	X	X	0	X	X	X	X	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR1.3.3	0	0	0	0	0	0	0	0	X	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR1.4	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR1.5	0	0	0	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR2 / FR2.1 / FR2.1.1	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FR2.1.2	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0
FR2.1.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0	0	0	0	0
FR2.2 / FR2.2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0
FR2.2.2	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	X	X	0	0	0	0	0	0	0	0	0	0
FR2.2.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0	0
FR2.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0
FR3 / FR3.1 / FR3.1.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	X	0	0	X	0	0	0	0	0	0	0
FR3.1.2	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0
FR3.1.3	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	X	0	X	X	0	0	0	0	0
FR3.2 / FR3.2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	X	0	0	0	0
FR3.2.2	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	X	0	0	X	0	0	0
FR3.2.3	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	X	0	0	0	0	X	X	0	0
FR3.3	0	0	0	X	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0
FR4	0	0	0	0	0	0	0	0	0	0	X	0	X	0	0	0	0	0	0	X	0	X	X	0	X	X	X	X

Figure 4. Final full design matrix, containing all the FRs and DPs located at the leaf-level.

2.2.3 End of the Decomposition Process

The complete sets sub-FRs and sub-DPs, placed along the different levels of the design hierarchy, are described in Figure 3. It can be seen that only the nodes which corresponding FR is or depends on a basic function of the transportation delivery service were actually decomposed. This is a consequence of the integration of the FAST model with Axiomatic Design Theory in the decomposition activities.

After all the leaf-levels in the different branches of the design hierarchy have been reached, and as stated by the value-based axiomatic decomposition method, the final full design matrix was constructed (Figure 4) to confirm the consistency of the lowest-level design decisions, in terms of the DM elements.

2.3 Discussion and results of the case study

The case study herein presented contributed to illustrate the applicability of the proposed value-based axiomatic decomposition method. The main findings from this study are summarised next:

- The value-based-decomposition method provided an iterative and systematic process to develop, in a consistently manner, the architecture of the transportation delivery service.
- The articulated use of the FAST model with Axiomatic Design principles proved to be useful to:
  - Identify the FRs that are associated with the basic functions of the transportation delivery service.
  - Distinguish the FR-DP pairs of the design hierarchy that should be considered as leaf (FRs associated with secondary functions and sub-FRs associated with support functions) from those that can be further decomposed (FRs associated with basic functions and sub-FRs associated with dependent functions).
  - Define a sufficient and necessary set of FRs in all levels of the design hierarchy.
  - Check the consistency of the sub-FRs with their corresponding parent level FR, by making use of the "How-Why" logic.
- The decomposition guidelines provided by Tate [1999], which the value-based method incorporates, were applicable.
- The final full design matrix (Figure 4), showing that design decisions led to a decoupled design, was important for the company since it indicated that the chance for rework during the service planning activities was minimal.

3 CONCLUSIONS

This paper illustrated a practical application of the decomposition method presented in part I that integrates the Axiomatic Design Theory with Value Engineering principles, in particular the Function Analysis System Technique (FAST). Each step of the proposed value-based axiomatic decomposition method was described and the results were presented and discussed.

The main findings that can be derived from this case study can be summarized as follows:

- The suggested value-based axiomatic decomposition method proved to be applicable and useful in a real design project.
- The use of the "How-Why" intuitive logic from FAST not only demonstrated to be useful in checking for design inconsistencies, but also revealed to be easily comprehended by the design project team.
- During the decomposition activities, and in each level of the design hierarchy, the proposed method helped to define a necessary and sufficient number of FRs, understand the relationships among FRs located at different levels of detail, and distinguish leaf from non-leaf FR-DP pairs.
- The result of the design process, which includes the decomposition activities, led to a decoupled design as showed by the final full design matrix (Figure 4). This provided a good decisional-order to be followed by the operational managers during the service planning activities, especially for time critical and non-standard transportation delivery services.

In future studies, we aim to test the proposed value-based decomposition method in the context of other design projects, including projects which make use of the Design for Six Sigma (DFSS) methodology, in order to improve the method itself and check its applicability to others contexts.

4 REFERENCES

[1] Bytheway C.W., *FAST Creativity & Innovation*, Florida: J. Ross Publishing, 2007. ISBN 1-932159-66-0

[2] Hintersteiner J.D., Friedman G. "System Architecture Template", *MIT White Paper*, Axiomatic Design Group, 1999.

[3] Mizuno S., *Management for Quality Improvement: The Seven New QC Tools*, New York, Productivity Press, 1988. ISBN 0-915299-29-1

[4] Suh N.P., *The Principles of Design*, New York: Oxford University Press, 1990. ISBN 0-19-504345-6

[5] Suh N.P., *Axiomatic Design: Advances and Applications*, New York: Oxford University Press, 2001. ISBN 0-19-513466-4

[6] Tate D., "A Roadmap for Decomposition: Activities, Theories, and Tools for System Design", *Doctoral Thesis*, Department of Mechanical Engineering, Massachusetts Institute of Technology (MIT), Cambridge, MA, 1999.