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Mathematical supply-chain modelling: Product analysis of cost and time

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Abstract. Establishing a mathematical supply-chain model is a proposition that has received attention due to its inherent benefits of evolving global supply-chain efficiencies. This paper discusses the prevailing relationships found within apparel supply-chain environments, and contemplates the complex issues indicated for constituting a mathematical model. Principal results identified within the data suggest, that the multifarious nature of global supply-chain activities require a degree of simplification in order to fully dilate the necessary factors which affect, each sub-section of the chain. Subsequently, the research findings allowed the division of supply-chain components into sub-sections, which amassed a coherent method of product development activity. Concurrently, the supply-chain model was found to allow systematic mathematical formulae analysis, of cost and time, within the multiple contexts of each sub-section encountered. The paper indicates the supply-chain model structure, the mathematics, and considers how product analysis of cost and time can improve the comprehension of product lifecycle management.

1. Introduction & Background

Since 1990 [1] evolving global supply-chain efficiencies has become a key driver in the race for retail prominence [2]; this notion was highlighted by [3], who said *"modern competition has shifted from company vs company, to supply-chain vs supply-chain"*. Recent global retail players [2] have shown awardable attributes and have provided other companies with unfathomable judgments on whether to manage responsive or efficiency supply-chains, when adopting stages for product development processes [4]. However, found within other current literature, many academics believe that there is a lack of applied strategic perspective on global sourcing [5] and a lack of performance measuring techniques [6], contributing to organisations being unable to fully encompass the analysis of a complete product lifecycle [7], throughout its supply-chain conception [8].

On that account and that of the absent mathematical supply-chain model [6]; it seems appropriate to aim for a suitable solution to this required dimension, of the modern day global supply-chain strategy. It has therefore, been suggested that there is a current need for the complex supply-chain components to be reconfigured, to allow a more comprehendible and holistic overview of the activities involved [6]. Consequently, this paper ventures towards a holistic model of the apparel supply-chain, whilst giving a concurrent mathematical algorithm, to enable future performance measures to transmogrify.

2. Theoretical PACTUM Model©: Incorporated research data and analysis

The collected data from the various research samples was converged with the methodical approaches to model formulation outlined by [9], together with constituents of the Six Sigma DMAIC problem solving practices [10]. This convergence of data and hypotheses gave a clear and systematic approach to the steps needed for the development of such a complex synergy. Therefore, instead of arranging quotations, graphs and charts as research data, the results from the methodology used in this research is presented in a graphical model simulation. This system of graphical representation of data allowed for the variables to be consolidated and simplified. Research conducted by [9] suggested that statistical learning techniques are a valuable tool for detecting complex relationships and interaction variables, which was indeed helpful in the mathematical model conception.

These approaches to research data management and data representation enabled the mathematical assessment of *effort* encountered within the complex apparel supply-chain, which is identified in figures 4-11. Consequently, the *'Product Analysis of Cost & Time Using Mathematical Modelling' (PACTUM Model©)* method is supported by the literature, primary data collected and was found to allow systematic mathematical formulae analysis, of cost and time, within the multiple contexts of each supply-chain sub-section encountered. This has then led to a holistic mathematical formula for calculating overall and divisions of *effort* (using the indexed sub-sections found in section 2.2.6.) whilst analysing each sub-section and/or entirety of a products lifecycle, when considering cost and time as the initial calculating factors.

2.1. PACTUM Model© mathematical formula

In order to understand the holistic mathematical model, the below equations describe the sum for calculating the *highest value* of total supply-chain effort:

2.1.1. Formula 1 & 2. The PACTUM Model© allows the calculation of *effort* (***E***), within each sub-section of the supply-chain to be measured; with the *sub-sections* of the supply-chain defined as (***i***); *costs* defined as (***c***); *time* is defined as (***t***) and the function of these sub-sections defined as (***F***):

$$E_i = F_i (c_i , t_i) \tag{1}$$

$$E_i = F_i (c_i , t_i) = \frac{1}{\sqrt{c_i^2 + t_i^2}} \tag{2}$$

2.1.2. Formula 3. In consideration of the holistic mathematical formula of the PACTUM Model©; formula 3 below describes how *effort* can be measured within a single products sub-section lifecycle. The values will ultimately range from *high effort* to *low effort*. Identified within indexed section 2.2.6., these values can be assigned by adding the effort values of each dependent variable:

$$\left(\sum_i E_i \right) \tag{3}$$

2.1.3. Formula 4. Significantly by observing the non-assumption that the effort value cannot be equalled too or larger than one, it can therefore be said that **1** is *the highest effort value* achievable. Most importantly, the lowest value assigned can only be determined by the nature of the organisations own differential supply-chain functions which must be defined by the model adopter, according to their own operational cost values, time frames and subsequent effectiveness:

$$E_i = \frac{1}{\sqrt{c_i^2 + t_i^2}} \tag{4}$$

2.2. PACTUM Model© graphical illustrations

Represented in a simple yet intuitive manner, by figure 4, the entire formation of the PACTUM Model© shows the converged functions, variables and relationships found within global supply-chains and product development process. However, it could be argued that this simplified representation of such complex synergies is lacking more problematical ascendants of current global supply-chain functions. To address this point, it has been considered that by the very nature of such complexities, the illustrated PACTUM Model© allows model adopters a more fluid approach, to supply-chain analysis, when considering their own differential organisational structures and product development strategies; Hence, allowing the variable supply-chain functions to be customised rather than prescribed.

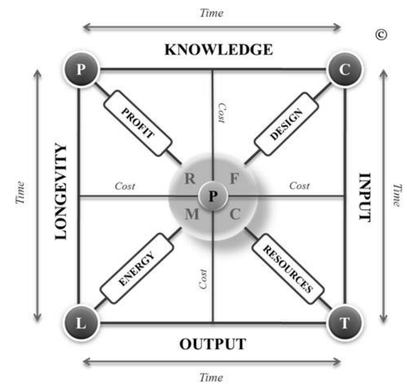


Figure 4. Holistic overview of PACTUM Model© The central point being (P) represents the actual product being developed.

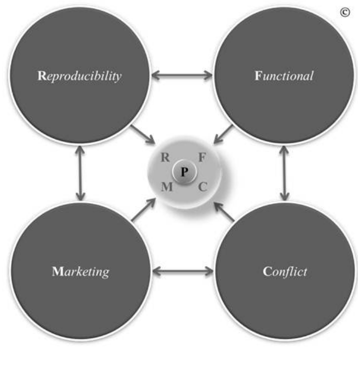


Figure 5. Illustration showing the four main independent variables of the supply-chain that affect the product during its entire lifecycle.

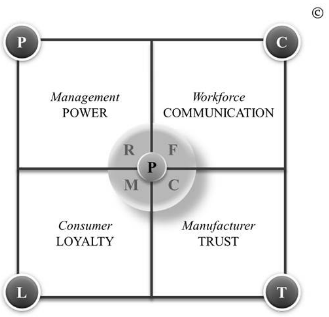


Figure 6. Illustration showing the four main dependent variables specifically associated with relationships and job functions of the supply-chain that are necessary to produce and sell a product during its lifecycle.

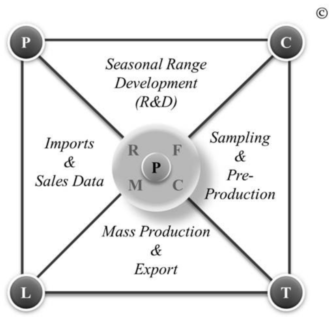


Figure 7. Illustration showing the four main dependent variables specifically associated with the processes found within the supply-chain that are necessary to produce and sell a product during its lifecycle.

2.2.1. PACTUM Model©: Dependent and independent variables. If we consider that figures 6 & 7 were laid on top of one another, it would be possible to appreciate that both the management and workforce have elements of human functional capabilities and engagement factor levels within the *seasonal range development* stages of the products lifecycle; simultaneously the workforce and manufacturer both have elements of human functional capabilities and engagement factor levels within the *sampling and pre-production* stages; the manufacturer and consumer both have elements of human functional capabilities and engagement factor levels within the *mass production and export* requirements; and the consumer and the management both have elements of human functional capabilities and engagement factor levels within the *import* necessity and subsequent *sales data*.

At this stage it is worth pointing out that the PACTUM Model© is able to uniquely divide the purpose of each supply-chains functional capabilities conducted; allowing an adopter of this model to define their own specific supply-chain practices (by using the suggested index in section 2.2.6. as guidance) and then tailor the functional elements/values of each sub-section, to their own organisational structure and product development strategies.

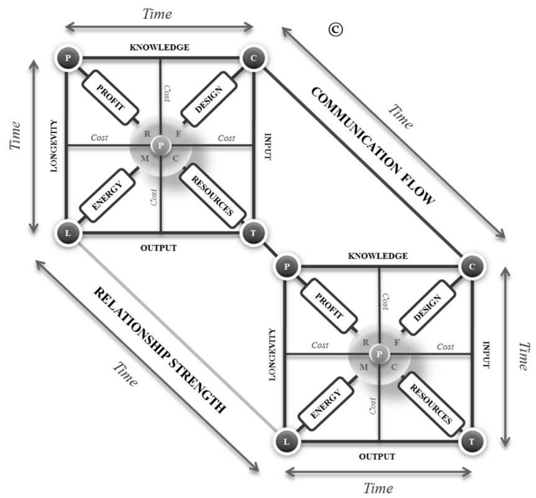


Figure 8. Illustration showing how the PACTUM Model© can be configured to represent a supply-chain of numerous organisational components and demonstrates the relationship of retailer and supplier engagement; with the top PACTUM Model© representing the calculations attributed to Primary Retail organisations and with the bottom PACTUM Model© representing calculations attributed to Secondary Supplier organisation.

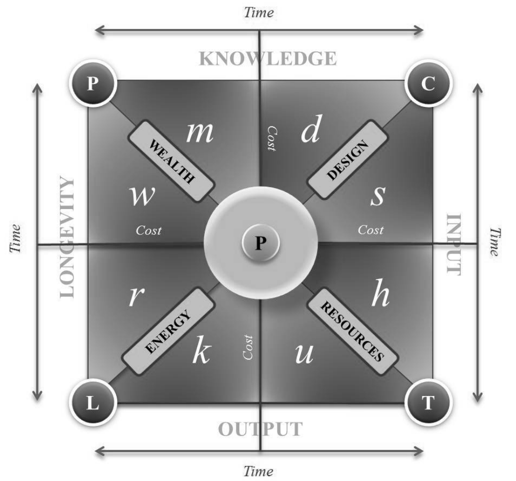
2.2.2. PACTUM Model©: Dependent effort functions. Written around the edge (vertically and horizontally) of figure 4 are the *dependent effort functions: Knowledge, Input, Output* and *Longevity*. These dependent effort functions are required in order to fulfill the variables outlined in figures 5, 6 and 7.

2.2.3. PACTUM Model©: Core dependent product functions. Illustrated by figure 4 are the core product functions that all other previously mentioned variables and functions are dependent upon, with these being: *Design, Resources, Energy and Profit*. These core dependent product functions are placed within the sub-sections of the PACTUM Model© that represent their attributed independent and dependent variables and functionalities as formerly illustrated and discussed.

2.2.4. PACTUM Model© sub-section index system. The following sections of this paper shows how the PACTUM Model© uses graphical representation, of each sub-section, to define the calculations by using a right-angled triangle to represent the variable values. For example, within the calculus of the *effort value* for the *knowledge/design* (***d***) sub-section, this is defined as ($\boldsymbol{E_i}$), costs as ($\boldsymbol{c_i}$) and time as ($\boldsymbol{t_i}$); and similarly within the *input/design* (***s***) sub-section and so on and so forth for all other sub-sections. Shown in the PACTUM Model© diagram (figure 4), the two right angles of the triangle denote either the sub-section(s) *functional costs* ($\boldsymbol{c_i}$) or the sub-section(s) *functional time* ($\boldsymbol{t_i}$) values, found within the supply-chain parameters. Consequently, the hypotenuse of the triangle (noted as not being of significant numerical / financial value) does however, allow for a visual and mathematical calculation of *effort (*$\boldsymbol{E_i}$*)*; which provides the hypotenuse a value which significantly correlate to that of the values assigned to the *costs* and *time* of the sub-section functionalities.

Accordingly, the man-made index (shown in section 2.2.6.) displays the variables relating to the main sub-sections of the supply-chain; these variables have been identified through the primary and secondary research. It should be noted that the variables within each of the eight indexed sub-sections, would inevitably be commensurate with organisational structure and specific supply-chain networks, yet there is sufficient flexibility to allow model adopters to enter their own differential financial and time frame calculations.

2.2.5. PACTUM Model© sub-section index. In relation to figure 9, the index below describes the arbitrary values and supply-chain functions which assess the *effort* grading system. The index also indicates the main titles given to the individual sub-sections which have been divided by using the supply-chains dependent variables:



2.2.6. Sub-section index.

m = Primary management
d = Primary R&D
s = Primary pre-production
h = Secondary pre-production
u = Secondary mass production
k = Third party logistics
r = Primary logistics
w = Primary product sales data
c = Costs
t = Time
E = Effort

Figure 9. Illustration of how the PACTUM Model© can visually show the highest *effort* values, assigned to the *costs* and *time* of each sub-section of the supply-chain encountered.

2.2.7. PACTUM Model© cost and time formulas. Using the model representation in figure 9 the PACTUM Model© is able to assess the defined indexed sub-sections, either by individual products, specific product categories, product ranges and total product output of an organisation.

Shown in figure 9 and using the index (in section 2.2.6.), it should be noted that the axis of the triangle associated with *costs* (***c***) is the actual monetary value (£) and changes according to the assessment required. For example: an individual product category may have a value associated with the total category budget. Similarly the axis of the triangle associated with *time* (***t***) is the actual time frame value which changes according to the assessment required for the period. Therefore these values of *cost*s and *time* are variable due to the nature of the predetermined product assessment and the nature of the organisation encountered.

Subsequently, the *effort total* (E_T) calculus for the supply-chain is dependent on the differential variables attributed to each organisation assessed and is expressed in formula 5. It is worthy of pointing out however, that these sub-section indexed variables may require high levels of *cost* and *time* in order to perform the functions required by each sub-section depending on the type of product being developed and supply-chain networks used. Illustrated by figures 10 & 11, the graphical PACTUM Model© simulations show how different product lifecycle practices can highlight variable degrees of *high effort* and *low effort* values, within each specific sub-section indexed.

$$E_T = \sum_i E_i = \sum_n \frac{1}{\sqrt{c_i^2 + t_i^2}} \quad (5)$$

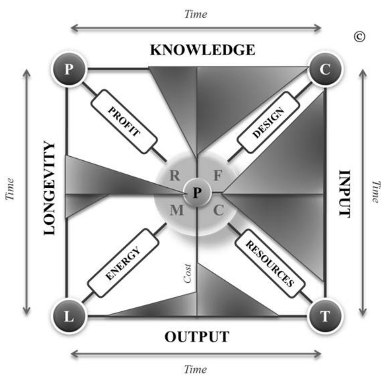


Figure 10. Illustration and an example of how the PACTUM Model© can visually show the effort values, of cost and time, aligned to each sub-sections of the supply-chain.

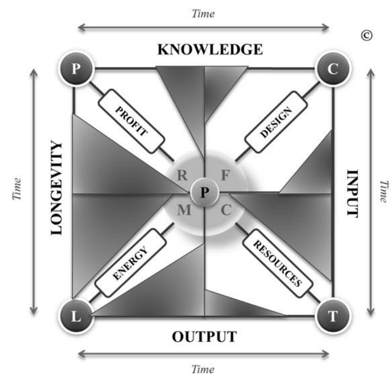


Figure 11. Illustration and an example of how the PACTUM Model© can visually show the effort values, of cost and time, aligned to each sub-sections of the supply-chain.

2. Conclusion & Recommendations

The methodical approaches to model formulation outlined by [9] and [10] were found to give a clear starting point and systematic approaches to the steps needed for the development of such a complex synergy. Thus, by highlighting the most significant *core dependent product functions, dependent effort functions*, *dependent variables* and *independent variables* found to be used within current supply-chain strategies; the PACTUM Model© represented by figure 4 allows potential model adopters to divide their differential organisational *functions, practices, employment roles and overheads,* into structured indexed sub-sections (considering their own specific cost and time values for each indexed sub-section). Significantly, this new method for calculating and comprehending product lifecycle functional capabilities within global fashion supply-chains; does allow a multitude of future research avenues which could provide accomplished academics and industry specialists incentive to develop collaborative links in order to produce a computer generated version of the PACTUM Model© (Intellectual Property rights apply).

Conclusively, the mathematical formulas will enable some established business leaders and academics to address the holistic nature of organisational variables, attributed to the *effort values* found within differential supply-chain environments and product development practices; to be calculated, analysed, evaluated, re-configured and critiqued in more depth than previously envisaged.

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