THE RELATIONSHIP BETWEEN PRODUCT ARCHITECTURE AND INNOVATION: A STUDY THROUGH DESIGN OF MOTORCYCLES

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ABSTRACT

How does the quantity and quality of innovation in an organization vary with the architecture of the product that the organization produces is a recurring theme in literature. This paper attempts to answer this question in quantitative terms and establishes an empirical relationship. While establishing this relationship, this paper also finds objective and quantitative expressions both for the product architecture and innovation in such a way that both the qualitative and quantitative aspects of innovation are accounted for. In this process three new formulations, which can be calculated using the data available in public domain, have been established for architectural modularity, architectural complexity and innovativeness of an idea respectively.These formulations have been verified by collecting innovation data in an automobile manufacturing company and analyzing it from the perspective of architecture and innovation. Finally, the relatioships between architectural parameters and innovativeness have been explored. Implications include the type of architecture more amenable to innovation, the impact of innovation on architectural complexity and a methodological contribution to operationalizing innovation.

Keywords: Product architecture, Complexity, Innovation, modularity

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1 INTRODUCTION

The relationship between product architecture and innovation has been subject of intense scrutiny. This question becomes critical from designer's perspective as product architecture is critical for design strategy and innovation is an ever- present goal. Scanning the literature for this relationship yields some useful conclusions. Meissner et al. (2021), Ulrich (1994), Ray et al. (2011), Galvin et al. (2020), Langlois (2002), Argyres et al. (2010), Pandremenos et al. (2009), Cabigiosu et al. (2013) and Macduffie (2013) and Jiao et al. (2007) suggest modularity, platforming and relating product family architecture to front-end customer requirement and back- end supply- side issues as solutions for innovation whereas Pandit et al. suggests dynamic organisational capabilities as solution for innovation. But there are two missing links in the studies done so far. Though Ulrich (1995), Chandra (2015), Chandra (2022) and Muffato et al. (2002) have provided definitions and frameworks for architecture and architectural complexity, a quantifiable architectural parameter which can be related to innovative ideas is still illusive. Another missing link is as Boer (2014) explicitly states that though the correlation between modularity and innovation is obvious, there has not been a robust relationship established so far. Similarly, many studies like Midgley and Dowling (2016), Ivanov (2021) and Lhuillary (2015) have provided various methods for quantifying innovation and innovativeness. But the missing link is the absence of a parameter which indicates a comprehensive parameter of innovativeness of an idea.

2 OBJECTIVE

So, what we can consider as established is the fact that innovation in a product is related to its architecture. But what remains to be established is whether this relationship is unidirectional or bidirectional. The major objective of this paper is to establish the exact nature of this relationship. This can be done only if we are able to identify the quantifiable aspects of both product architecture (architectural parameters) and innovation (innovation parameters). So, we break this objective into the following research questions:

1. What are the parameters of product architecture which relate to innovation and how can we quantify or determine these parameters?
2. What are the quantitative aspects of innovation (innovation parameters) which relate to product architecture and how can we quantify or determine these parameters?
3. What are the relationships between these architectural and innovation parameters and how do we establish this relationship.

3 METHODOLOGY

We chose a manufacturer of motorcycles and scooters for the purpose and collected the innovative ideas implemented in the company between a period from 1989 to 2018 after detailed study of spare parts catalogues of various models manufactured by the company, which were available in the public domain. Then we decided details of change and the architecture before the implementation of the ideas. For example, the spare parts catalogue for one of the oldest versions of one of the models showed a metallic fender with fastening arrangement (as shown in fig 2, top- left)), whereas the catalogue for one of the later models showed a plastic fender (fig-2, top- right), thus clearly featuring an innovative idea. Similarly, the perusal of, the oldest catalogue showed a mechanical clutch whereas one of the catalogues showed a centrifugal automatic clutch (as shown in fig- 2, bottom)), thus highlighting a radical innovative idea. But before we move on to the operational part. It was essential to clear the theoretical framework.

3.1 Step 1: Identification and quantification of architectural parameters

Ulrich (1995) defines product architecture as allocation of components to functions and provides a framework for product architecture in form of three elements- functions, components, and interfaces. He also provides a classification of architecture in form of integral, slot, bus, and sectional. The question that we need to address is that while looking for correlation of architecture and innovation, which are the aspects of architecture which can be correlated with innovation. This leads to two aspects of this correlation- the quantifiable aspects of product architecture (parameters) affecting innovation and those affected by innovation. This needs an investigation of various facets of product

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architecture, which we can consider for correlating to innovation. These are: (a) The construction of the components i.e., the elements and the complexity of their relationships (b) The allocation of the components to functions (c) The types of interfaces between the components i.e., coupled, or decoupled (d) The classification of architecture i.e., integral, sectional, slot, or bus. Ulrich classifies interfaces as coupled and decoupled interfaces. This provides a good basis for quantification of architecture. In fact, coupled or decoupled architecture is an aspect of modularity of architecture and there is a wide agreement on the fact that modularity helps innovation. Another aspect of architecture, which may relate to innovation is architectural complexity. It makes it imperative for us to formulate a method of quantifying these architectural aspects applicable across the areas of design and which we can applied based on publicly available data.

(a)Modularity: For calculating modularity, we propose a simple solution, which we propose to call 'degree of decoupling' which we define as the ratio of the number of decoupled interfaces to the total number of interfaces and look for correlating this ratio to the level of innovation. Testing the validity of this formulation, we find that this formulation takes care of both the difficulties enumerated earlier. Not only is the degree of decoupling eminently quantifiable but we can compare it across the board irrespective of the type of architecture or the construction of the components.

(b)Complexity: Scanning the universe of research in Complexity in product architecture, we find three types of observations:

Definition: Toepfer and Naumann (2016), Garina et al. (2018), Corso et al (2001), Shamsuzzoha et al. (2022) and Jacobs (2007) are all the view that the architectural complexity of a product is a function of number of elements, the number of relationships and the allocation of functions to components. Marty (2007) brings two other elements i.e., the diversity of elements and relationships and their weightages. Blackenfelt (2001) and Henriksson (2017) have shown that we can resolve the difficulties arising out of product complexity by creating modularity.

Quantification: Marty (2007) provides a formulation which is based on two separate elements-functionality and physical complexity. This formulation has three difficulties. The first is the fact that the formulation does not result in a single numerical value which makes the comparison of systems based on complexity difficult. Second is the fact that the functional importance of a component or element does not affect the complexity a very insignificant function like music system in a car can increase the complexity if it is the most complex system of all. And finally, the variety of components and relationships should not be a factor for complexity. The Sinha et al. (2013) provides the second formulation where we can calculate the structural complexity of system by adding the sum of component complexities to the product of number of pair- wise interactions and effect of architecture on interfaces. Again, this formulation has a difficulty that it does not provide the formulation for individual component complexity.

Resolution: To resolve the difficulties enumerated above, we can define complexity as multiplicity of links and relationships. So, we can define the architectural complexity as a parameter accounting for: (a) Number of parent child relationships or hierarchical links (C_{cp}) (b) Number of physical interfaces where element is physically connected (C_p) (d) Design interfaces or design dependencies (C_d) (d)Function links or allocation of functions to components (C_l). Now, we need to explore a parameter which objectively quantifies the architectural complexity of a system. Extending the Muffatto's complexity definition that defines complexity as function of function mapping and interface coupling and considering the relationships listed in the preceding section, we define architectural complexity as per the following equation.

$$AC= \log (C_{cp}.C_i.C_l) \tag{1}$$

This formulation needs to be tested for efficacy and validity. The prerequisites for any formulation to calculate the architectural complexity of a mechanism are- (1) The formulation should consider the elements of complexity i.e., the number of parts and relationships, the number of interfaces and the allocation of functions to elements. (2) The formulation should result in zero for a mechanism without any complexity i.e., a single element with a single function allocated to it. This necessitates a log function. (3) Any increase or decrease in the value of input elements should result in a proportionate change in the resultant value. The second and third prerequisites necessitate a relationship of multiplication between input values. (4) The number of physical and design interfaces should have an additive relationship resulting into a mean value as the two types of interfaces may mean the same interface in some cases. (6) The final value resulting from the formulation should be comprehendible. A value resulting in thousands, or millions may become incomprehensible. This also makes the log

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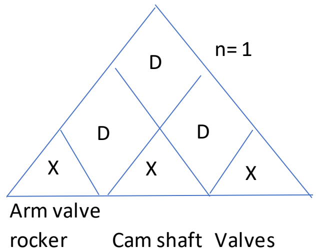
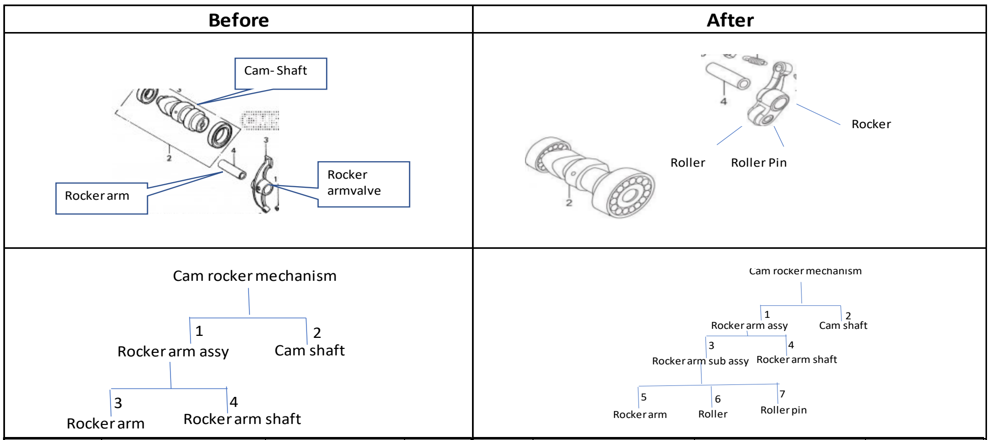
function a suitable choice. Since, the formulation as defined by equation (1) satisfies all these prerequisites, we can consider it to have efficacy and validity.
Here, an example is illustrated for calculation of degree of decoupling and architectural complexity.
To illustrate the formulation through an example, we consider the idea where the rocker arm (which acts as the follower to the cam) for the valve timing mechanism has been modified from a simple arm rubbing against the cam to a roller rotating because of cam movement. As we can see in fig-1 (top), all three interfaces before the innovation are decoupled interfaces, we can calculate the degree of decoupling can by dividing the number of decoupled interfaces (i.e.,3) by the total number of interfaces (i.e.,3) and thus we get n=1. Now, we consider the complexity before and after applying the idea. We can tabulate the physical interfaces, the design interfaces and the function links and the percentage change can be calculated as shown in the figure 0 (bottom left and right).





	Physical interface (i_p)			Design interface (i_p)			Function link
Elements	ARV	Shaft	Cam Shaft	ARV	Shaft	Cam Shaft	Valve Timing
Arm Valve Rocker					1	1	1
Shaft Rocker arm	1			1		1	1
Cam Shaft	1	0		1	1		1
External	1	1	1	1	1	1	

	Physical interface (i_p)					Design interface (i_p)					Function link		
	ARV	Shaft	Cam Shaft	Roller	Roller Pin	ARV	Shaft	Cam Shaft	Roller	Roller Pin	Valve Timing	Roller Rotation	Friction Reduction
Arm Valve Rocker							1	1	1	1	1	0	1
Shaft	1					1		1	0	0	1	0	0
Cam Shaft	1	0				1	1		1	0	1	1	1
Roller	0	0	1			1	0	1		1	1	1	1
Roller Pin	1	0	0	1		1	0	0	1		0	1	0
External	1	1	1	0	0	1	1	1	0	0	4	3	3
	4	1	2	1	0	5	3	4	3	2			

	Before	After
Ccp	4	7
Cp	5/3= 1.67	8/5= 1.6
Cd	9/3= 3	17/5= 3.4
Ci	2.335	2.5
Cl	3/1= 3	10/3= 3.33
AC	log (4*2.335*3) =1.3226	log (7*2.5*3.33) = 1.7655
Percentage change= (1.7655- 1.3226)/1.7655 X100= 25.08%		

Figure 1: Interface diagram (top) and system- diagram, parent- child links, interfaces, and function- links and complexity calculation before (bottom-left) and after (bottom-right) the innovation.

3.2 Step 2: Create a framework for quantification of innovation

Webster's dictionary defines 'innovation' as a new idea, device, or method. It translates into new or alternative designs in technological domain. Since none of the models referred quantify innovativeness in a way which helps in innovativeness of an idea to the architecture of the product, we attempt to formulate an index which incorporates the two elements- innovation level and the impact of innovation. Altshuller (1999), Zlotin et al. (2020), and Souchkov (2007) have defined various levels of innovation. But the framework which is easiest to define and classify is provided by Henderson and Clark (1990), which clearly differentiates between different types of innovation based on the

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combination of interfaces and technology. This quadrant provides us with a ladder of innovations in the order of the content and radicality. The best thing with this model is that it is quite easy to identify the level of innovation. The only thing that we must add from our side is a number attached to each level signifying the content and radicality. So, we propose the table shown above (Table 1).

Table 1: Innovation levels, Cost reduction index and performance Improvement Indices

				Performance Indices				
Innovation Level		Cost Reduction Index		Category Index			Quantum Index	
Incremental	1	No cost reduction	1	Basis	4	e.g. Fuel Efficiency	Radical	3
Modular	2	Very small cost reduction (C<0.1%)	4	User Comfort	3	e.g. Seating comfort	Nominal	2
Architectural	3	Modest cost reduction (0.1%<C<1%)	8	Feature Addition	2	e.g. Mobile charging	None	1
Radical	4	Big cost reduction (C>1%)	12	None	1			

A study by Magnusson (2003) becomes useful, where he has shown through a study of Alstom and Toyota that architectural innovation takes a greater mobilization of knowledge, money, and supply chain than modular change. So, architectural change must be rated above the modular as it radically affects the product functioning as well as its semantics. As far as quantifying the impact of innovation is concerned, it can be safely said that any innovation in a product has only two purposes- cost reduction or performance improvement (this improvement may be in terms of efficiency, functions, ergonomics, appearance, or feature addition). So, we can quantify the impact of innovation in a product by multiplying the two impacts. The cost reduction impact can be expressed in terms of percentage with respect to the total cost, but we simplify the rating by assigning weightage '4' for very small reduction (where the reduction is less than 0.1% of the total product cost), '8' for modest reduction where the reduction in cost is less than 1% of the total product cost and '12' for big reduction (more than 1%). For quantifying impact on performance, we have simplified the Ziv- Av and Reich's (2003) model who propose a system function matrix based on the strength of relationship between system and function. If this matrix is to be adapted for an innovative idea, the matrix is reduced to one functional parameter and one performance parameter and therefore a one-by-one matrix. Therefore, the core concept can be adapted for an innovative idea by multiplying the quantum of change (Quantum index) in the performance (again by rating them nominal or radical) and the gravity of the function (category index) they are impacting. So, we get the table as shown. Finally, we calculate the innovativeness index of an idea by the relationship.

$$II = LCP/(LCP)max = \text{LCP/48} \quad (2)$$

Where II= Innovativeness index, L= Innovation level, C= Cost reduction index P= Impact on performance = Quantum index (QI). Category index (CI). It may be noted that cost reduction index values have been fixed at 1, 4, 8 and 12 to ensure parity between maximum values of C and P. Dividing LCP by (LCP)max ensures that the index maintains a scale of 0 to 1.

Now let us take an example to illustrate this. To illustrate the example for innovation leading to cost reduction, we discuss a metallic fender fastened on to the frame of a motorcycle as shown in fig-2 (top- left). Here we can observe that the frame is interfaced with all parts like tail-light, winker and number plate through a decoupled interface except with fender which is fastened to frame through a coupled interface as any change in frame will cause a change in fender and vice- versa. The innovative idea was to design the fender in plastic material as shown in top- right of the figure. Now since the change is modular. (As the change is standalone with tail-light, winkers and number plate remaining the same and the bracket tail- light merged in the fender itself), the innovation level is 2. Since the purpose of this change is cost reduction and the quantum of the cost- reduction is less than 1% of motorcycle cost, the cost reduction index is 8 and hence the innovativeness index comes out to be 16/48= 0.33. In another example where the innovation leads to product improvement the clutch is replaced by automatic clutch as shown fig- 2 (bottom left and right). The innovation level in this example is radical, the cost reduction is zero, the category index (rider comfort) is 3 and the quantum of improvement is radical. So, L=4, C= 1, P= 3*3= 9. Hence, II= LCP/48= 4*1*9/48= 0.75.

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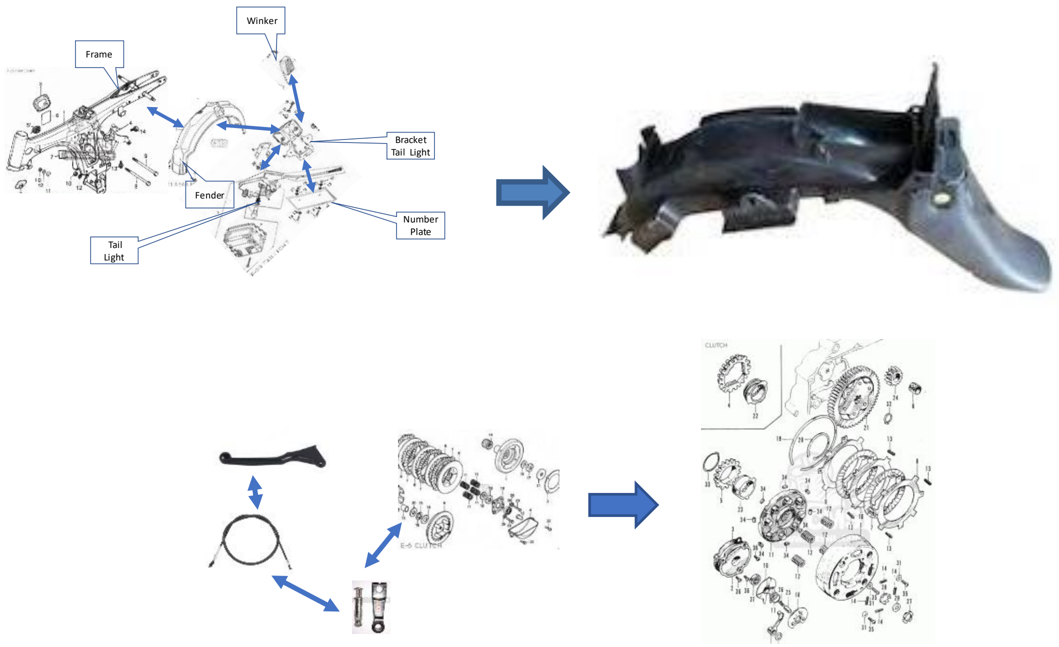


Figure 2: Rear fender and interfacing parts before innovation (Top-left) and rear fender after innovation (top- right) rear conventional clutch (Bottom-left) and centrifugal automatic clutch (Bottom- right) (All actuating parts like handle lever, cable and actuation lever are removed.)

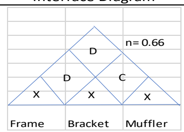
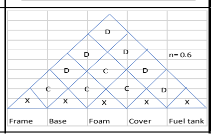
3.3 Step 3: Collect data for innovative ideas already implemented

The first and basic step is to collect the innovative ideas which have been implemented. For this we selected a manufacturer of two wheelers making scooters and motorcycles. The ideas are spread over many models. Some ideas are implemented as a continuous change in the same model and some ideas needed a new model to be created to implement it. The ideas are listed in Table-3.

3.4 Step 4: Calculation

The next step was to classify the ideas based on architecture and innovation ladder.
We assigned indices discussed earlier like cost reduction index, quantum index, category index and the innovation level index to each idea. We calculated the innovativeness index for each idea was by using equation (1). We created the partial house of architecture for each idea, as it existed before the implementation of the idea, was to classify the interfaces as coupled or decoupled. We classified the interfaces where the interfacing component can be modified or changed just by keeping the interfacing area same as decoupled and where it was not possible without altering whole of the interfacing component was classified as coupled interface as shown in table- 2. (This list in not exhaustive, due to space limitation, and has been shown in this table as an example to explain the process).

Table 2: Examples for innovative ideas and the interface diagram for degree of decoupling

S.No	Innovation Idea	Before Innovation	After innovation	Interface Diagram
1	Muffler mounting bracket integration			
2	Seat base metallic to plastic		Material changed to plastic	

We calculated the degree of decoupling by dividing the number of decoupled interfaces by total number of interfaces. Similarly, we calculated the architectural complexity before and after the implementation

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of the innovative ideas using equation (2) and the percentage of change was accordingly. Based on these steps we get the list of ideas along with Degree of Decoupling, Innovativeness Index, and percentage change in complexity due to the innovative idea as shown in the table- 3.

Table 3: The list of ideas with calculation of innovativeness index, degree of decoupling and change in complexity

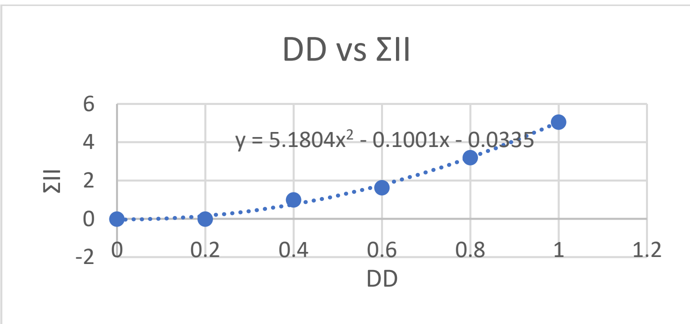
		ƒ Cha				Performance Improvent (P)					Complexity			
S.No	Innovation Idea	Level	Type**	Impact*	CR Level	Category Index (x)	Quantum Index(y)	x*y	Inn. Index II=LCP/48	Degree of Decoupling	C1	C2	Complexity Change	% Change
1	Muffler mounting bracket integration	3	2	C	4	1	1	1	0.25	0.66	0.778151	0.477121	-0.30103	-38.68528
2	Seat base metallic to plastic	3	1	C	8	1	1	1	0.5	0.66	1.642662	1.522444	-0.1202181	-7.318491
3	Rear fender metal to plastic	3	1	C	8	1	1	1	0.5	0.7	1.409933	1.197281	-0.2126526	-15.08246
4	Rear fender unification	3	1	C	8	1	1	1	0.5	0.7	0.623249	0.079181	-0.544068	-87.29541
5	Front fendar metallic to plastic	3	1	C	8	1	1	1	0.5	0.6	1.352183	0.887054	-0.4651281	-34.39833
6	Sari guard and woman pillion step unification	3	2	C	4	1	1	1	0.25	1	0.845098	0.618048	-0.2270499	-26.8667
7	Air filter and battery box unification	3	2	C	4	1	1	1	0.25	0.6	1.229938	0.896251	-0.3336871	-27.13041
8	Frame sheet metal to tubular	2	1	C	8	1	1	1	0.3333333	0.85	1.447158	1.447158	0	0
9	Side cover metal to plastic	2	1	C	4	1	1	1	0.1666667	0.77	1.021189	1.021189	0	0
10	Tool box metal to plastic	2	1	C	4	1	1	1	0.1666667	1	0.39794	0.39794	0	0
11	Battery box metal to plastic	2	1	C	4	1	1	1	0.1666667	1	0.822822	0.822822	0	0
12	Start stop mechanism	4	3	P	1	4	2	8	0.6666667	0.9	2.038223	2.574899	0.53667635	26.330605
13	Temp resistant seat cover	1	1	P	1	3	2	6	0.125	0.7	1.174351	1.174351	0	0
14	Glowing stripes	4	1	P	1	2	3	6	0.5	0.66	0.424882	1.759758	1.33487683	314.17617
15	Comfortable Pillion step	3	2	P	1	3	3	9	0.5625	1	1.240967	1.356361	0.11539342	9.2986685
16	Unification of caution marks	3	3	C	4	1	1	1	0.25	1	1.197281	0.477121	-0.7201593	-60.14959
17	Direct Front logo	3	2	C	4	1	1	1	0.25	1	1.255273	1.145507	-0.1097653	-8.744343
18	Automatic clutch	4	2	P	1	3	3	9	0.75	0.9	2.225374	2.60921	0.38383619	17.248166
19	Rotary gear to directly shift to neutral gear	2	2	P	1	3	3	9	0.375	0.6	1.695922	1.695922	0	0
20	Air suction valve to dilute CO concentration in e	4	2	P	1	4	2	8	0.6666667	1	1.354301	1.84514	0.49083966	36.243038
21	Friction reduction in Arm valve rocker	4	2	P	1	4	2	8	0.6666667	1	0	0	0	#DIV/0!
22	Sliding utility carrier as an option for rear seat	4	1	P	1	2	3	6	0.5	0.33	1.154546	1.702431	0.54788484	47.454583
23	Detachable seat for rear	4	1	P	1	2	3	6	0.5	0.66	0.653213	0.954243	0.30103	46.084542
24	Fuel collector to avoid fuel spillage on ABS parts	3	2	P	1	4	2	8	0.5	0.66	1.14442	1.459392	0.31497241	27.522447
25	Horn strip removal	1	1	C	4	1	1	1	0.0833333	1	0.574031	0.574031	0	0
26	Canister positioning to stop evaporative emissio	1	2	P	1	4	2	8	0.1666667	0.8	1.283301	1.283301	0	0
27	Multi-reflector lens to replace plane reflector ar	3	2	P	1	2	2	4	0.25	0.85	1.079181	1.146128	0.06694679	6.2034797
28	Fuel cap change to avoid vapour spillage	3	2	P	1	4	2	8	0.5	0.33	1.350732	1.652125	0.30139297	22.313299
	* C= Cost reduction P= Performance Improvement		Innovation Level:		1= Incremental 2= Modular 3= Architectural 4= Radical						** 1= Slot 2= Sectional 3= Bus			

4 RESULT ANALYSIS

For correlating architecture with innovation, we need to see the effect of decupling on innovativeness index and the effect of innovative index on complexity. Banding the II values within DD bands of 0.2, we get a graph and table as shown in fig 4. So, finally we can safely conclude that the relationship between the degree of decoupling in architecture and the total qualitative and quantitative value of innovative idea is a second order relationship expressed by

$$y = Ax^2 + Bx + C \quad (3)$$

Where y= ΣII= Sum of innovativeness indices of all ideas, x= DD= Degree of decoupling and A, B and C are constants.



DD	ΣII
0	0
0.2	0
0.4	1
0.6	1.625
0.8	3.208333
1	5.0625

Figure 4: Scatter diagram (left), table for DD vs ΣII (centre) and DD vs ΣII graph (right)

We plotted the impact of the innovative ideas on the percentage change in complexity based on innovation classification (ref figure- 5) i.e., innovation quadrant and innovation objective (performance improvement or cost reduction).

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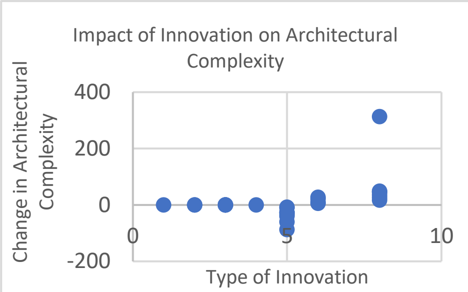

Type of innovation:	
1	Cost reduction, incremental
2	Perf. Improvement, incremental
3	Cost reduction, modular
4	Perf. Improvement, modular
5	Cost reduction, architectural
6	Perf. Improvement, architectural
7	Cost reduction, radical
8	Perf. Improvement, radical

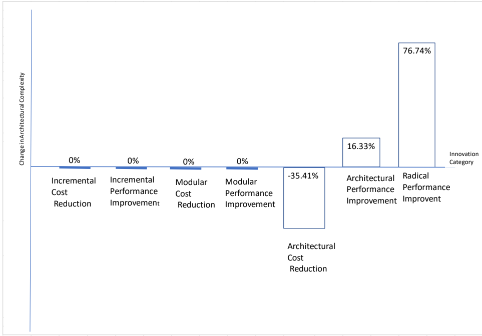

Figure 5: Scatter diagram (left), types of innovation (centre) and types of innovation vs impact on complexity (right)

This graph gives two obvious conclusions: (a)There is no or insignificant impact on the architectural complexity of a mechanism in case of incremental and modular innovations. This is logically explainable as in case of incremental changes, there is no or negligible change in either the number of components or interfaces or functional allocations. (b) Architectural complexity always increases in case of performance improvement ideas whereas it almost always decreases in case of cost reduction ideas. Analyzing further, we plotted another graph for mean values of percentage change in complexity for each type of innovation as shown in diagram (fig-5 right). This result clearly shows that on average, the percentage change increases for performance improvement as we go up the ladder on innovation quadrant.

5 CONCLUSIONS

Since, we have identified the parameters, done the quantification and established the relationship, all objectives and research question have been met well. This exercise has many flaws like the list not being exhaustive, the number of ideas not being huge enough and near absence of parts with bus architecture. Nevertheless, we can safely draw the following conclusions:

- Degree of decoupling is a fairly accurate parameter to gauge and quantify the architectural potential for innovation and it is most relevant and relatable to innovation potential and most simple and easy to calculate.
- Though there are innumerable frameworks available for quantification of innovativeness potential of a product or organisation, almost all of them render an outside analyst helpless due to the confidentiality of data needed to quantify innovation. In this scenario, the framework suggested in this paper provides a viable alternative to quantify the innovation potential of a product with least information needed which can be termed confidential.
- There is a direct relationship between the degree of decoupling in the products or components and the cumulative innovativeness index.
- Component designs with integral architecture are not advisable for innovative ideas to flourish. We can understand this easily as with integral architectures degree of decoupling is either zero or extremely low and any innovative idea gets bogged down due to changes that must be conducted in the interfacing parts and the modularity gets severely compromised.
- It is highly advisable to have parts with high degree of decoupling because it results in increase in both the numbers of ideas and the innovativeness of ideas.

6 LIMITATION AND FUTURE SCOPE

- The foremost limitation of this study is its limited scope i.e., design of 2-wheeler parts, which is not sufficient to arrive at a satisfactory conclusion. Even if we limit the scope to 2-wheeler component design, we should study many manufacturers. But, more importantly, if the formulations derived in the study are to achieve any credence, we should include diverse types of products with diverse architectures.
- Another limitation is related to availability of data. The data used in this study is based on spare-parts catalogues. This limitation is imposed by confidentiality of data as companies are not

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willing to share design related data. Even the spare- parts catalogues are not made available in public domain by all companies. Keeping in view this limitation, we limited the formulation to data made available through the spare- parts catalogue.

- The above two limitation make it exceedingly difficult to conduct a study which is more broad-based with sufficient data. But we need to conduct a study by taking a broad- based sample of industries and products involving diverse types of architectures. Moreover, we need to compare the architecture and innovation parameters with previous studies.
- We need to study the impact of decoupling on various aspects of manufacturing separately.

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