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Introducing a Unique Inventory Control Framework for Centralized VMI and JIT Production

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Abstract: The purpose of this research is to develop a new Information Fractal Structure (IFS) framework to facilitate communication and collaboration between centralized Vendor-Managed-Inventory (VMI) and Just-In-Time production to optimize inventory and logistics cost throughout the supply network. The proposed framework is conceptually developed, validated and implemented using mathematical and simulation modelling. Experimental factorial design and statistical techniques (MANOVA) are used to generate and analyze the results. The results demonstrated that the application of the proposed IFS provided a new effective collaboration protocol between centralized VMI and core manufacturer. Furthermore, the IFS led to an increase in both collaboration and integration and improve the process of sharing information across the network, which has proven to be a problematic area for industrialists.

Keywords: Fractal supply network, supply network modelling, inventory optimization, centralized Vendor-Managed-Inventory, Just-In-Time production.

1. INTRODUCTION

In recent decades, raw materials and finished goods inventories have become more significant in the supply chains. Traditionally, the necessity of efficient management of inventories, to protect them against theft and possible damage and using a suitable method for inventory turnover, were considered. However, holding inventories can bring enormous costs for the firms that do not create any value added. In response to this problem, the Just-In-Time inventory management system has been the focus for many years. Just-In-Time is a comprehensive control system for production and inventory management. In this system, raw materials will not be bought, and production will not be started if demand is not received. The primary objective of this system is to reduce or eliminate inventory from raw materials to finished goods at all stages of production. Under ideal conditions, a company with Just-In-Time inventories management system only purchases its daily material requirements; there is no work in process at the end of the day and all finished products offered to the customer immediately during the day (Garrison et al., 2010).

Vendor Managed Inventory (VMI) as an innovation system has been conducted in relation to supply chain management in the 1980s (Blatherwick, 1998) and most of the scholars' attention has been focused on examining its benefits (Lee and Cho, 2014). VMI is a mechanism that unifies operational activities in the supply chain in terms of inventory management, transportation planning, pricing policies, etc. In the VMI model, the supplier has the responsibility to meet customers demand and control their inventory (Kumar and Kumar, 2003; Lee and Ren, 2011). It brings some benefits for members, who participate in the supply chain including a decrease in inventory level and lead time, a moderate intensification effect of demand deviation and improvements in service level (Claassen et al., 2008). VMI has been conducted as a superior approach to reducing inventory cost in the supply chain in comparison to traditional approaches (Dong and Xu, 2002; Yao et al., 2007).

In the traditional supply operation mode, decentralized VMI is the focus. Decentralized VMI has some disadvantages including high investment cost, high VMI operation cost and a lack of information sharing among them. The frequency of the delivery of high-quality components in small shipments and low cost is one of the most important principles of the JIT concept (Banerjee and Kim, 1995). In this mode, suppliers must produce and keep large batches in the VMI warehouse near to the site of manufacture and deliver components frequently in small batches which cause some problems. Firstly, each supplier has to invest in building warehouses or rent third-party storage facilities to manage or completely outsource to third-party logistics, which incurs high investment costs. Secondly, each of the suppliers has a system for implementing VMI operation. If each supplier provides components on a small scale, maintaining its VMI system requires a high running cost. As a result, the total cost of the VMI systems in the whole supply link is very high. Thirdly, as each supplier runs its own VMI storage independently and dispersedly, there is a lack of information sharing among them. Inevitably, distortion and delay of supply information and demand information occurs, which makes suppliers unable to meet the needs of manufacturers quickly, accurately, and simultaneously. Therefore, centralized VMI, as a new collaborative operation mode, has been introduced to resolve the aforementioned problems and facilitate Just-In-Time (JIT) production using JIT delivery (Li, Gao, and Ran, 2012). Hence, in this research, by developing an information fractal structure, new collaboration between centralized VMI and core manufacturer is introduced which centralized VMI scheduling replenishment quantity-frequency to core manufacturer by identifying optimum cycle stock of the

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manufacturer based on its inventory information to achieve the lowest logistics costs by integrating both inventory holding cost and transportation cost (Saad and Bahadori, 2015). In comparison to the other information structure, information fractal is distinguished due to its capabilities such as self-similarity, self-optimization, self-organization, goal orientation, and dynamics (For more detail see Saad and Bahadori, 2019).

2. THE PROPOSED FRAMEWORK FOR THE INFORMATION FRACTAL STRUCTURE (IFS)

Fig. 1 displays the proposed framework of the Information Fractal Structure (IFS) which is consists of:

- An "information fractal-core manufacturer" linked with several of information fractal work centers belong to production unit where manufacturing activities are performed and
- An "information fractal-centralized VMI" with an information fractal VMI center and information fractal supplier's facilities.

For each of these information fractals, there are five function models namely: observer, analyzer, resolver, organizer and reporter to form the basis of the information fractal unit structure. Fig. 2 demonstrates this structure and clearly explains the internal relationships amongst these five function models. This research paper concentrates on two main functions, analyzer and resolver, to optimize both the safety stock and replenishment frequency.

Information fractal work centers in the core manufacturer analyze the demand from next work center or customer, optimize their safety stock and determine the optimal reorder point and share their demand and inventory information with the source fractal. It is important to determine how much inventory must be held against the variability in both demand and lead times. Therefore, understanding the demand variability is essential to calculate safety stock. Thus, analyzers in the fractals use an appropriate method to analyze demand based on a set of demand statistics. During the demand analysis process, demand is aggregated, outliers are recognized, and a set of demand statistics are provided to determine the demand classification (e.g. Slow, Lumpy, Erratic and Smooth) (For more detail see Saad and Bahadori, 2018).

Once analyzers have finished the demand analysis, resolvers start to specify the required safety stock by considering demand and lead-time variability. Resolvers use a target service level to calculate optimum safety stock. Service level is a measure to indicate a fractal's ability to provide products to downstream fractals. There are different types of service level which are used in industry, including type 1 (the probability of not stocking out), type 2 (fill rate) and type 3 (ready rate). In this research, service level type 1 is used. Resolvers in the core manufacturer determine the safety stock level and reorder points as part of the safety stock optimization. There are three models to calculate safety stock and reorder points which may happen during the demand period (For more detail see Heizer and Render, 2014, p.511):

- Demand is variable and lead time is constant
- Lead time is variable and demand is constant
- Both lead time and demand are variable

Subsequently, the information fractal VMI center traces and observes manufacturer's components demand and inventory information from work centers which are located in the first step of the production lines. Then, share the components demand with supplier's facilities and more importantly, scheduling replenishment quantity-frequency based on optimum replenishment cycle stock to core manufacturer aiming to minimize the total logistics costs.

for this purpose, the analyzer in information fractal VMI center have to calculate the inventory holding costs in the core manufacturer and analyze transportation costs by investigating different days between replenishment (*DBR* = *1*,..., *x*) during the demand period. Since different numbers of days between replenishments (*DBR*) were investigated among fractals by the analyzer, the resolver integrates both the inventory holding costs and transportation costs to achieve lower total logistics cost among fractals to choose the best match and find the optimum amount of replenishment cycle stock (*RCS*) (see equations (1) &(2) respectively).

The following notations are adopted:

- *SSj*: Safety stock of component *j*
- *DBR*: Days between replenishment
- *TDj*: Total demand of component *j*
- *T*: Period time
- *t*: Transportation time
- *V*: Component value
- *I*(*cc*)%: Inventory carrying cost percentage
- *T*(*c*): Transportation cost
- *td*: Travel distance
- *A*(*c*): Average transportation cost per mile.
- *μd*: Average daily demand

$$Min\left\{\left[\left(SS_j + DBR \times \left(\frac{\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j}{2T}\right) + \left(\frac{\left(\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j\right)t}{T}\right) \times V \times \frac{T}{365} \times I_{(cc)\%}\right]\right. + \left[\left(td \times \frac{\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j}{DBR \times \mu_d}\right) \times A_{(C)}\right]\right\} \quad (1)$$

$$RCS = DBR \times \left(\frac{\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j}{2T}\right) \quad (2)$$

Then, Resolver will attempt to select the optimum shipment quantity (*SQ*) and number of shipments (*NOS*) (see equations (3) and (4) respectively) which can lead to determine the optimum types of transportation assets as well (Saad and Bahadori, 2016).

$$SQ = DBR \times \mu_d \quad (3)$$

$$NOS = \frac{\sum_{j=1}^{n} SS_j + \sum_{j}^{n} TD_j}{DBR \times \mu_d} \quad (4)$$

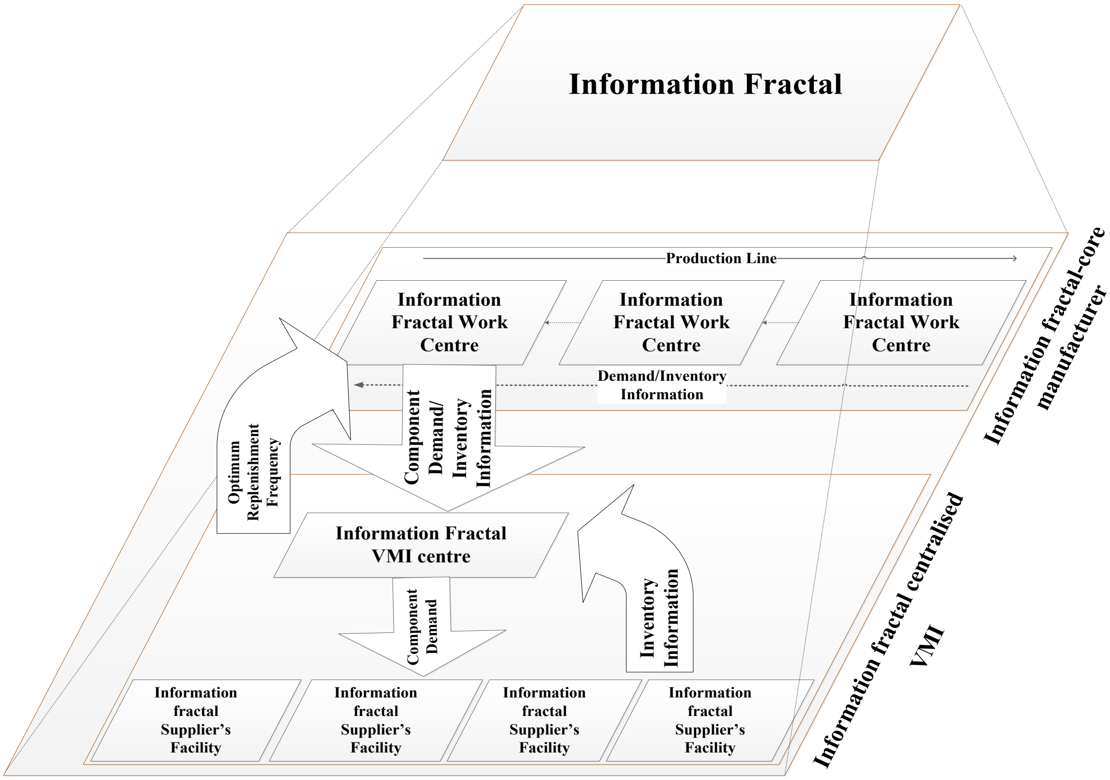

Fig. 1. The Proposed Information Fractal Structure (IFS)

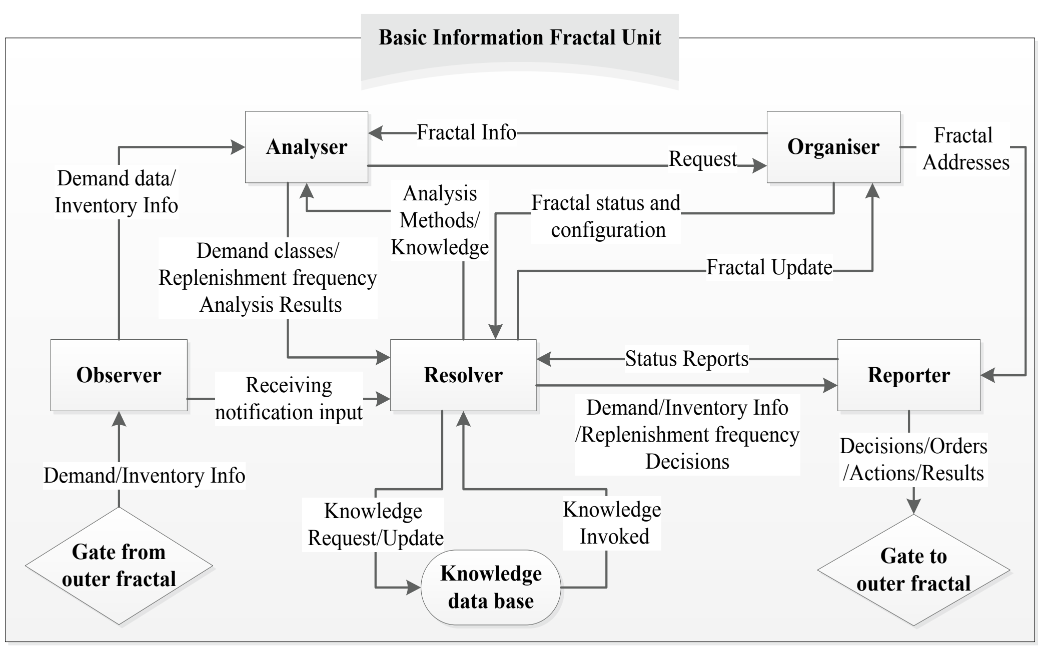

Fig. 2. Basic Information Fractal Unit Structure

3. APPLICATION OF THE PROPOSED INFORMATION FRACTAL STRUCTURE

To apply the proposed structure, a hypothetical core manufacturer and a centralized VMI are considered and created using LlamaSoft (2018). LlamaSoft allows an agent-based representation of the supply chain infrastructure and their behavior and interactions while enabling a process-oriented approach to representing orders as in a discrete event simulation. Therefore, the agents here are the observer, analyzer, resolver, organizer and reporter; however, only two main functions, analyzer and resolver are considered.

The manufacturer deals with three different products (K1, K2 and K3) which are produced by three production lines (A, B, and C) respectively as shown in Fig. 3 where:

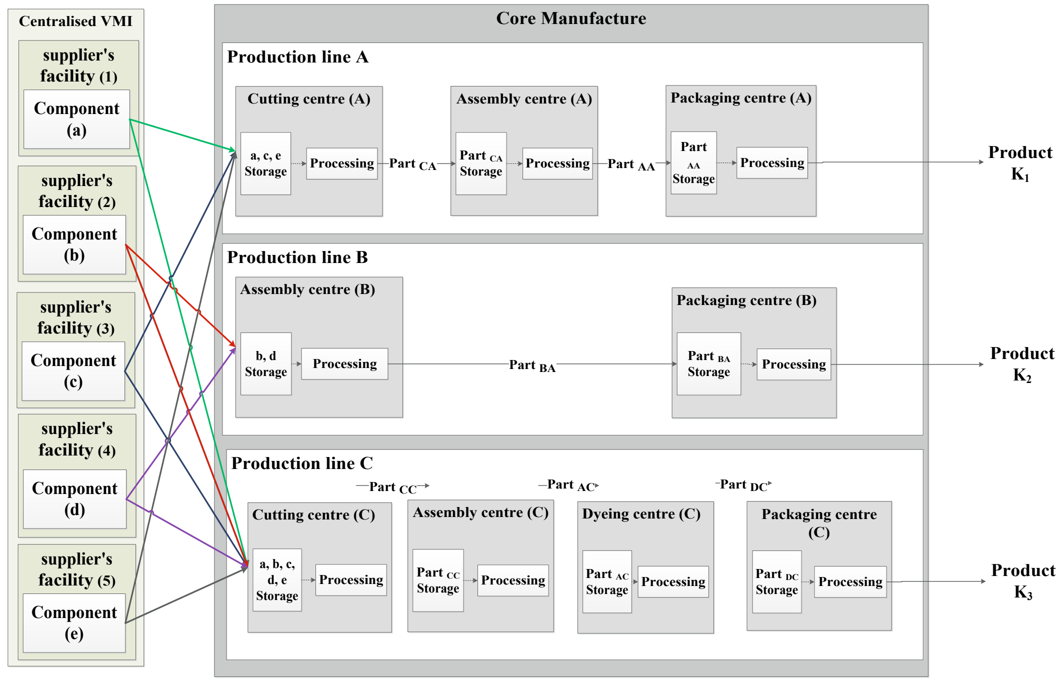

Fig. 3. Centralized VMI, core manufacturer structure and components flow mapping

- Production line A consists of three different centers, namely cutting center (A), assembly center (A) and packaging center (A) to produce K1.
- Production line B comprises two different centers which are assembly center (B) and packaging center (B) to produce K2.
- Production line C made up of four different centers; cutting center (C), assembly center (C), Dyeing center (C) and packaging center (C) to produce K3.

The centralized VMI has been built closer to the main manufacturer (150 miles from core manufacturer) and comprises of five supplier's facilities belonging to worldwide suppliers in which:

- Supplier's facility (1) deals with a single component (a) with a value of $10.
- Supplier's facility (2) deals with a single component (b) with a value of $50.
- Supplier's facility (3) deals with a single component (c) with a value of $20.
- Supplier's facility (4) deals with a single component (d) with a value of $ 60.
- Supplier's facility (5) deals with a single component (e) with a value of $10.

Production line's demand of one-month test period for the components has been aggregated over 5 weeks seven days per week as shown in table 1.

Table 1. Weekly aggregated demand of production lines

Production Line	W(1)	W(2)	W(3)	W(4)	W(5)
A	4050	3990	5640	6270	2910
B	2832	3766	3376	3178	3458
C	8370	8480	8020	7120	10055

Moreover, there are some other assumptions as follows:

- Lead time required to supply components from centralized VMI to core manufacturer and parts among centers in the manufacturer is fixed as 1 day.
- The percentage of inventory carrying cost (*I*(*cc*)%) is assumed to be 12 percent of total value of inventory. In practice, this percentage is identified by senior managers in the company.
- There is a transportation system from a third party with two types of transportation assets to ship components from centralized VMI to core manufacturer, namely; Full Truck Load (TL) with capacity of more than 2000 components with average transportation cost per mile ($A_{(c)}$) of $1 and Less Than Truck Load (LTL) with capacity of less than 2000 components with average transportation cost per mile ($A_{(c)}$) of $1.5.
- Days between replenishment (*DBR*) should not be more than 5 days.

3.1 Experimental design

This section provides the design of experiments which allow us to find out the impact of the uncertainties in the demand, days between replenishment (*DBR*) and component demand mix on the performance of centralized VMI and core manufacturer which is consisted of the three production lines as shown in fig. 3. Four performance measures (dependent factors) namely transportation cost, inventory holding cost, cycle stock and total logistics cost are considered in this study. After conducting pilot experiments, the three independent factors with their levels are identified and displayed in Table 2.

Table 2. Independent factors with their levels

Factor	Levels				
Demand	1000	Normal (1000,100)	Normal (1000,200)	Normal (1000,300)	-
(*DBR*)	1 Day	2 Days	3 Days	4 Days	5 Days
Component Demand Mix	$\sum_{j=1}^{3} SS_j + \sum_{j}^{3} TD_j$	$\sum_{j=1}^{2} SS_j + \sum_{j}^{2} TD_j$	$\sum_{j=1}^{5} SS_j + \sum_{j}^{5} TD_j$	-	-

4. RESULTS ANALYSIS AND DISCUSSION

A full statistical factorial MANOVA technique was used to analyze the results obtained from GURU Simulation Software at 95% confidence interval. Based on full factorial experimental design, a total of 60 experiments are required to gather enough data and to allow the authors to draw a valid conclusion from this study. Since, in this case demand and demand mix were dependent to each other; demand factor has been used as covariate variable. The obtained results can be concluded as follows:

- Days between replenishment (*DBR*) has significant relationship with transportation costs, inventory holding costs, total logistics costs and cycle stock.
- Demand and component demand mix have a significant relationship with inventory holding costs and total logistics costs, however, it is appeared that both transportation and cycle costs are not significantly affected by the demand or demand mix.
- Interaction between days between replenishment and Component demand mix (*DBR * Component Demand Mix*) show that there is a significant relationship with performance measures except transportation cost.

In order to achieve optimum replenishment cycle stock (*RCS*), the analyzer in the information fractal VMI center calculated inventory holding costs of the first working center located in the production lines in the core manufacturer and also specified transportation cost from centralized VMI to core manufacturer by investigating different days of replenishment from 1 day to 5 days.

To achieve the lowest total logistics cost from centralized VMI to core manufacturer, resolver used analyzer's results to determine optimum replenishment cycle stock by integrating both the inventory holding costs and transportation costs with respect to different days of replenishment to choose the best match of inventory holding cost and transportation cost. The results proved that during the demand of one-month test period for packaging of components (a), (c) and (e) to Cutting center (A), the lowest logistics cost can be achieved with day between replenishment of five days (see Table 3). While, for package of components (b) and (d) to Cutting center (B) with days between replenishment of four days (see Table 4) and finally for package of components (a), (b), (c), (d) and (e) to Cutting center (C) with days between replenishment of four days as shown in Table 5.

Table 3. Total logistics cost at different DBR (1 day to 5 days) from centralized VMI to Cutting center (A)

DBR	Inventory Holding Cost ($)	Transportation Cost ($)	Total Logistics Cost ($)
1	323	7425	7748
2	417	3826	4243
3	520	1723	2243
4	620	1308	1928
5	**709**	**1055**	**1764**

Table 4. Total logistics cost at different DBR (1 day to 5 days) from centralized VMI to Cutting center (B)

DBR	Inventory Holding Cost ($)	Transportation Cost ($)	Total Logistics Cost ($)
1	794	7425	8219
2	1219	3816	5035
3	1555	2585	4140
4	**1855**	**1308**	**3163**
5	2125	1056	3181

Table 5. Total logistics cost at different DBR (1 day to 5 days) from centralized VMI to Cutting center (C)

DBR	Inventory Holding Cost ($)	Transportation Cost ($)	Total Logistics Cost ($)
1	1367	7425	8792
2	1790	2550	4340
3	2189	1800	3989
4	**2575**	**1350**	**3925**
5	2936	1050	3986

Thus, substituting the above optimum obtained DBR values in equation 2 then the optimum replenishment cycle stock (*RCS*) for packaging of components to production line (A), (B) and (C) are 2094 components, 1206 components and 3055 components respectively.

Since the replenishment cycle stock from centralized VMI to the manufacturer was optimized; the resolver will then use equation (3) and (4) to calculate, the optimum number of shipment (*NOS*) during the period and optimum shipment quantity (*SQ*) as follows:

- Optimum numbers of shipment from centralized VMI to cutting center (A) is seven shipments while for both cutting center (B) and cutting center (C) there are nine shipments during the demand of a one-month test period.
- Optimum quantity per shipping from centralized VMI to cutting center (A), cutting center (B) and cutting center (C) are 3690, 2144 and 5420 components. Since the optimum quantity per shipping to cutting centers was more than 2000 components per shipment, therefore the transportation assets assigned should be a Full Truck Load (TL).

5. CONCLUSIONS

In this paper, a new information fractal structure consists of "*information fractal core manufacturer*" and "*information fractal centralized VMI*" was proposed to facilitate communication and collaboration between centralized Vendor-Managed-Inventory (VMI) and Just-In-Time production to optimize inventory and logistics cost throughout the supply network. Fractals in the core manufacturer analyze the demand from next production step or customer, optimize their safety stock and determine the optimal reorder point and share their demand and inventory information with the source fractal. Information fractal VMI center traced core manufacturer demand and share it with supplier facilities and determined optimum replenishment cycle stock by integrating both inventory holding costs in the core manufacturer and transportation costs from centralized VMI to core manufacturer to achieve the lowest logistics cost by investigating the days between replenishment and scheduled optimum delivery frequency to core manufacturer.

The proposed framework was applied to the proposed hypothetical supply network using mathematical modelling and LlamaSoft Supply Chain GURU Simulation Software with results being analyzed and validated using a statistical test (MANOVA).

Application of the proposed framework has clearly introduced a unique inventory control framework based on JIT inventory concept and has led to an increase in both collaboration and integration throughout the supply network.

In relation to future work, each information fractal structure should consist of five functions namely; observer, analyzer, resolver, organizer and reporter, this article focused only on analyzer and resolver functions, it would be very beneficial to expand the proposed framework to include the other three functions in order to be a representative of a complete “Information Fractal”.

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