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An Analysis of Key Labour Productivity Factors in the Construction Industry

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Abstract—The construction industry is critical for enhancing the productive capacity of the overall Indian economy. Being Labour intensive, Labour Productivity becomes an extremely vital performance measurement tool within the industry. But the present landscape is that of an un-organized sector which becomes evident to be synonymous with the kaleidoscope of unregulated, poorly skilled and low-paid workers. An essential ingredient to counteract this issue is the successful application of science, recognized as the systems approach which can be made to attack civil-systems' problem. This paper focuses on the key factors affecting labour productivity in the field. Their analysis is performed using Interpretive Structural Modeling (ISM), a system approach, which yields the inter-relations and the inter dependencies among the factors. A digraph is sketched to diagrammatically represent the same. Further, the rationale behind the key elements of the system is discussed.

Index Terms— Labour Productivity, Interpretive Structural Modeling, System approach, Digraph, Construction Management

1 Introduction

CONSTRUCTION is a labour intensive process. Manpower is one of the productive resources in construction. Hence, the construction productivity largely depends upon human performance [10], [12]. The construction industry labour system is a large section suffering from poor working conditions and adverse terms of work. While defining an unorganized sector we can say that construction labours are a part of the workforce which has not been able to organize in pursuit of a common objective because of constraints such as; casual nature of employment, ignorance and illiteracy, small size of establishments with low capital investment per person employed, scattered nature of establishments, superior strength of the employer, etc. [9], [11].

Productivity simply refers to the general efficiency of an organization or individual. The output of any aspect of production per unit of input is termed as productivity. Productivity can also be defined as an economic measure of output of a worker, machine or an entire national economy in the creation of goods and services to produce wealth [2]. A company that most minimizes input and maximizes output has the highest productivity. Productivity in general is a total concept that addresses the key elements of competition i.e. innovation, cost, quality and delivery. It must be viewed as value adding in addition to optimizing the cost and quality of construction [3].

Reliable measures of labour productivity are output per work-hour being achieved by workers. For any complex problem under consideration, a number of factors may be related to the issue or problem. However, the direct and indirect relationships between the factors describe the situation far more accurately than the individual factor taken into isolation [10], [12].

A system is a constitution of elements along with the inter-relationships, inter relations and inter dependencies among them. The process starts with certain system-related data, ideas, skills; and /or knowledge residing in the various participants, and ends with an enhanced understanding of the system by the participants, individually and collectively. The basic mathematical entity common to the tools to represent the system is a **structural model**. A structural model is simply a collection of elements and their relationships. Graphically these models are represented by a set of nodes with some or all the nodes connected by lines [5]. **Interpretive Structural Modeling** (ISM) is one such structural modeling tool which has an added advantage compared to other structural modeling with respect to its factor analyzing capacity and ease of handling.

2 Objective

The objective of the work is three fold, namely:

To analyze the elements affecting labour's productivity in the construction industry using Interpretive Structural Modeling (ISM).

To establish the interactions, inter-relationships and the inter dependencies among these factors and form a digraph.

To thereby, establish the key elements to be focused for the enhancement of labour productivity

3 Labour Productivity

Productivity growth is important to any individual enterprise, an industry or an economy. The importance of productivity in construction industry is that it is an extremely vital performance measurement tool within the construction industry. Due to the size of construction industry productivity trends carry immense consequences for the economy as a whole [7].

Two measures of construction productivity are available: (1) Total Factor Productivity (TFP), where all outputs and inputs are considered; and (2) Partial Factor Productivity (PFP), often referred to as single factor productivity where outputs and single or selected inputs are considered [1].

Total Factor Productivity is defined as the ratio of outputs

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to the summation of all inputs, and is expressed as shown below. All input resources may include, but are not limited to, labour, material, energy, capital and plant. Total Productivity is a comprehensive measure that accounts for all outputs and inputs whether tangible or intangible [1].

$$\text{Total Factor Productivity (TFP)} = \frac{\text{Total Output}}{\sum \text{of all input resources}}$$

Partial Factor Productivity establishes a relationship between outputs and a single or selected set of inputs. Labour productivity is thus a Partial Factor Productivity, where only the input of labour is considered. Hence, Labour Productivity can be expressed as shown below,

$$\text{Labour Productivity} = \frac{\text{Output Quantity}}{\text{Labour hours}}$$

It is widely acknowledged that the informal sector in India suffers from a low productivity syndrome, compared to the formal sector. Poor human capital base; in terms of education, skills and training; as well as lower mobilization status of the work force further adds to the vulnerability and weakens the bargaining strength of workers in the informal sector [9]. This raises the need to study and research the Labour Productivity in the construction sector as a system.

4 Interpretive Structural Modeling (ISM)

ISM is a tool which permits identification of structure within a system. It was first proposed by J.N. Warfield in 1973 to analyze the complex socioeconomic systems [10]. Interpretive Structural Modeling(ISM) may be defined as a process which is aimed at assisting the human being for better understanding what one believes and to recognize clearly what one does not know. It enables individuals or groups to develop a map of the complex relationships between the many elements involved in a complex situation. Its basic idea is to use expert's practical experience and knowledge to decompose a complicated system into several sub-systems and construct a multi level structural model. ISM is often used to provide fundamental understanding of complex situations, as well as to put together a course of action for solving a problem [6].

The significance of any structural modeling method is its wholistic process in which the user aspires to gain an overall appreciation of the system as a whole by studying a structural model of the elements which comprise the system [5].

4.1 Methodology

In this technique, a set of different directly and indirectly related elements are structured into a comprehensive systematic model. The method is interpretive in that the group's judgment decides whether and how items are related; it is structural in that, on the basis of the relationship, an overall structure is extracted from the complex set of items; and it is modeling in that the specific relationships and overall structure are portrayed in a digraph model. Therefore, ISM develops insights into collective understandings of these relationships [11].

The various steps involved in ISM modeling are as follows [10].

Step 1: Structural Self-Interaction Matrix (SSIM): Keeping in mind the contextual relationship for each factor and the existence of a relationship between any two factors (i and j), the associated direction of the relationship is questioned. The following four symbols are used to denote the direction of relationship between two factors (i and j):

(a) V for the relation from factor i to factor j (i.e., factors i will influence factor j);
(b) A for the relation from factor j to factor i (i.e., factor I will be influenced by factor j);
(c) X for both direction relations (i.e., factors i and j will influence each other);
(d) O for no relation between the factors (i.e., barriers i and j are unrelated). Based on the contextual relationships, the SSIM developed.

These points are represented in Table 1.

TABLE 1
STRUCTURAL SELF INTERACTION MATRIX SYMBOLS

SSIM Symbol	i → j	j → i
V	✓	x
A	x	✓
O	x	x
X	✓	✓

Step 2: Reachability Matrix: The next step in ISM approach is to develop an initial reachability matrix from SSIM. For this, SSIM is converted into the initial reachability matrix by substituting the four symbols (i.e., V, A, X or O) of SSIM by 1s or 0s in the initial reachability matrix.

TABLE 2
SUBSTITUTION OF SYMBOLS IN REACHABILITY MATRIX

SSIM Symbol	i → j	j → i
V	1	0
A	0	1
O	0	0
X	1	1

The rules for this substitution are as follows, also represented in Table 2:

a) If the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0.
b) If the (i, j) entry in the SSIM is A, then the (i, j) entry in the matrix becomes 0 and the (j, i) entry becomes 1.
c) If the (i, j) entry in the SSIM is X, then the (i, j) entry in the matrix becomes 1 and the (j, i) entry also becomes 1.
d) If the (i, j) entry in the SSIM is O, then the (i, j) entry in the matrix becomes 0 and the (j, i) entry also becomes 0.

Following these rules, the initial reachability matrix is prepared [6], [10], [11].

Step 3: Level Partitions: From the final reachability matrix, for each factor, reachability set and antecedent sets are derived. The reachability set consists of the factor itself and the other factor that it may impact, whereas the antecedent set consists of the factor itself and the other factor that may impact

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it. Thereafter, the intersection of these sets is derived for all the factors and the levels of different factor are determined. The factors for which the reachability and the intersection sets are the same occupy the top level in the ISM hierarchy. Once the top-level factor is identified, it is removed from consideration. Then, the same process is repeated to find out the factors in the next level. This process is continued until the level of each factor is found. These levels help in building the digraph and the ISM model.

Step 4: Conical matrix: Conical matrix is developed by clustering factors in the same level across the rows and columns of the final reachability matrix. The driving power of the factor is derived by summing up the number of ones (1s) in the row and its dependence power is derived by summing up the number of ones (1s) in the columns. Next, driving power and dependence power ranks to the factors that have the maximum number of 1s in the rows and columns, respectively.

Step 5: Digraph: From the conical form of reachability matrix, the preliminary digraph including transitive links is obtained.

Step 6: ISM model: Digraph is converted into an ISM model by replacing nodes of the factors with statements.

Step 7: MICMAC analysis: Matrice d'Impacts croises- Multiplication applique an classment (cross-impact matrix multiplication applied to classification) is abbreviated as MICMAC. Based on the driving power and the dependence power, the factors, have been classified into four categories, i.e. autonomous factors, linkage factors, dependent and independent factors.

i. Autonomous factors have weak driving power and weak dependence power. They are relatively disconnected from the system, with which they have few links, which may be very strong
ii. Linkage factors have strong driving power as well as strong dependence power. These factors are unstable in the fact that any action on these factors will have an effect on others and also a feedback effect on themselves.
iii. Dependent factors have weak driving power but strong dependence power.
iv. Independent factors have strong driving power but weak dependence power.

A factor with a very strong driving power, called the 'key factor' falls into the category of independent or linkage factors.

5 Analysis of Labour Productivity Factors

The labour system in the construction industry constitutes of a large number of elements that are interlinked and interconnected, which influences a labour's productivity. The major elements contributing to the system has been considered for analysis in this paper. They are labour experience, provision of incentives and motivation, communication between labours and supervisors, training of the labour, planning of construction activities beforehand, method of working, supervision, insecure feeling of labours at site, labour inattentiveness.

Lack of skill and experience of labour is detrimental to the productivity of the construction process. If the candidate does not possess enough experience, he must be given training on site which is quite uneconomical on a larger scale. Labour experience is an element corresponding to a labour's age, circumstances of prior projects related to a specific activity at site [1].

Motivated labours usually are more enthusiastic and initiative. They work harder and respond faster to instructions. Their pace is, moreover, associated with a greater sense of pride, satisfaction, and responsibility, thus they typically achieve more, in comparison with demotivated or discouraged labourers. In almost all cases, motivation cannot replace experience, activity training, or education [1].

Communication between labours and supervisors is an essential element in the labour system. The ability of the supervisor to make understand the labour of the specificities of the work and the capability of the worker to understand and put forward his doubts and needs at site is equally important in terms of wastages, safety.

Specific activity training refers to the education provided to workers before they begin working on a particular activity. Poorly trained and unskilled labours are commonly characterized with low and faulty outputs coupled with unjustifiably high inputs. In addition, their outputs are almost always rejected, either in whole or in part, by the inspecting engineer, resulting in extensive and expensive rework, rectifications, or repairs. To the contrary, experienced labours possess sound intellectual abilities, practical solutions to encountered obstacles, and high technical and motor skills, all of which lead to higher productivity, lower cost of labour, and better quality of finished outputs [1], [4].

Proper planning of activities corresponds to the scheduling of activities, management of men and material at site, housekeeping, formwork setting and scaffolding works. If proper scheduling is not done, it leads to unexpected risks during execution of the work.

The wrong use of construction methods aside from slowing down productivity of workers could gravitate to rework with the waste of material and human resources [8].

Lack of supervision encourages labours, especially those who are under the direct employment method, to engage in unproductive activities, take frequent unscheduled breaks, wait idle, or even leave the job sites during working hours to attend to personal matters. Direct supervision of labour is required to avoid faulty and non-conforming work to contractual specifications and thus minimize the expensive incidents of rework and the associated delays to activities at hand [1]. This element is more prominent in large scale projects where the current supervisor must oversee several projects at once [2].

Insecure feeling to the labour while working at heights, improperly fixed scaffoldings, lack of safety equipments and other unsafe conditions affects the labour's efficiency at work.

Payment delay is a factor that leads to extensive absenteeism among the labours, in turn leads to distrust on the employer. It greatly occurs when the project economy is not favourable to the employer, and he tries to cut costs by reducing the number of labours at site or not paying them as promised.

Labour inattentiveness is a factor leading to loss in labour productivity. It relates to the labour's attitude in general, unfulfillment of his basic needs, dissatisfaction with the supervisor or the construction activity in general or due to unusual illness when at site.

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5.1 Applying ISM to the Labour Productivity

The contextual statement taken for the pair wise comparison is "Element 'i' influences element 'j' with respect to labour productivity".

The factors are given a number as follows:

F1 – Labour Experience
F2 – Motivation and incentives
F3 – Communication between labour and supervisor
F4 – Training of the labour
F5 – Non-planning of construction activities
F6 – Method of working
F7 – Supervision
F8 – Insecure feeling of labour at site
F9 – Payment delay
F10 – Labour inattentiveness

A group of field experts, namely, consultants, site engineers, supervisors, contractors were asked to determine the contextual relationship between the listed labour productivity system elements. Based on the majority opinion, the Structural Self Interaction Matrix (SSIM) is formulated which is shown in Table 3. Using the symbol conversion, the reachability matrix is formed as shown in Table 4. Further analysis is done based on the methodology discussed earlier. The reachability set, antecedent set and intersection set of the factors are identified (Table 5). The level partition is done by iterating the Tables (Table 6, Table 7, Table 8, Table 9).

TABLE 3
STRUCTURAL SELF INTERACTION MATRIX

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	X	O	V	A	V	V	O	V	O	V
F2		X	X	O	O	V	A	O	A	V
F3			X	O	V	V	A	O	A	V
F4				X	O	V	O	V	O	O
F5					X	V	A	V	A	O
F6						X	A	V	A	O
F7							X	V	O	V
F8								X	O	O
F9									X	V
F10										X

TABLE 4
REACHABILITY MATRIX

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	DP¹
F1	1	0	1	0	1	1	0	1	0	1	6
F2	0	1	1	0	0	1	0	0	0	1	4
F3	0	1	1	0	1	1	0	0	0	1	5
F4	1	0	0	1	0	1	0	1	0	0	4
F5	0	0	0	0	1	1	0	1	0	0	3
F6	0	0	0	0	0	1	0	1	0	0	2
F7	0	1	1	0	1	1	1	1	0	1	7
F8	0	0	0	0	0	0	0	1	0	0	1
F9	0	1	1	0	1	1	0	0	1	1	6
F10	0	0	0	0	0	0	0	0	0	1	1
DP²	2	4	5	1	5	8	1	6	1	6	

DP¹ – Driving Power; DP² – Dependence Power

TABLE 5
LEVEL PARTITION ITERATION 1

	Antecedent set	Reachability set	Intersection set	Level
F1	1,3,5,6,8,10	1,4	1	
F2	2,3,6,10	2,3,7,9	2,3	
F3	2,3,5,6,10	1,2,3,7,9	2,3	
F4	1,4,6,8	4	4	
F5	5,6,8	1,3,5,7,9	5	
F6	6,8	1,2,3,4,5,6,7,9	6	
F7	2,3,5,6,7,8,10	7	7	
F8	8	1,4,5,6,7,8	8	1
F9	2,3,5,6,9,10	9	9	
F10	10	1,2,3,7,9,10	10	1

For the next iteration, factors with level 1 in the previous iteration (here, F8 and F10) are eliminated from the Antecedent set, Reachability set and the intersection set of the level partition table. The procedure is continued in the forthcoming iterations.

TABLE 6
LEVEL PARTITION ITERATION 2

	Antecedent set	Reachability set	Intersection set	Level
F1	1,3,5,6	1,4	1	
F2	2,3,6	2,3,7,9	2,3	
F3	2,3,5,6	1,2,3,7,9	2,3	
F4	1,4,6	4	4	
F5	5,6	1,3,5,7,9	5	
F6	6	1,2,3,4,5,6,7,9	6	2
F7	2,3,5,6,7	7	7	
F9	2,3,5,6,9	9	9	

TABLE 7
LEVEL PARTITION ITERATION 3

	Antecedent set	Reachability set	Intersection set	Level
F1	1,3,5	1,4	1	
F2	2,3	2,3,7,9	2,3	3
F3	2,3,5	1,2,3,7,9	2,3	
F4	1,4	4	4	
F5	5	1,3,5,7,9	5	3
F7	2,3,5,7	7	7	
F9	2,3,5,9	9	9	

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TABLE 8
LEVEL PARTITION ITERATION 4

	Antecedent set	Reachability set	Intersection set	Level
F1	1,3	1,4	1	
F3	3,	1,3,7,9	3	4
F4	1,4	4	4	
F7	3,7	7	7	
F9	3,9	9	9	

TABLE 9
LEVEL PARTITION ITERATION 5

	Antecedent set	Reachability set	Intersection set	Level
F1	1	1,4	1	5
F4	1,4	4	4	6
F7	7	7	7	5
F9	9	9	9	5

As the left out factor in the iteration 5 is F4, it obviously gets placed in level 6.

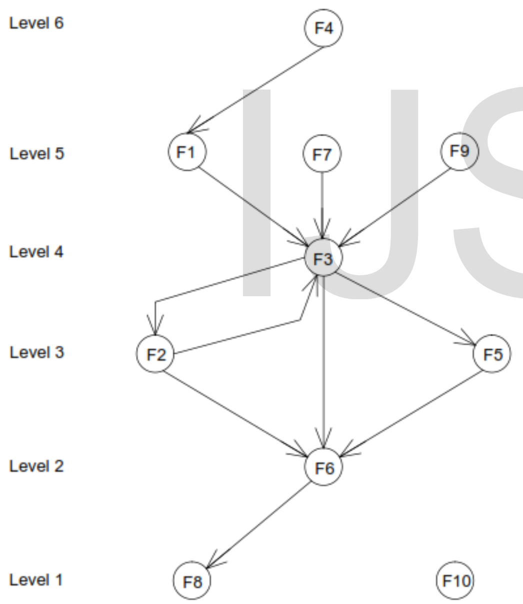

Fig. 1 Digraph : Direct Links in the Labour Productivity system

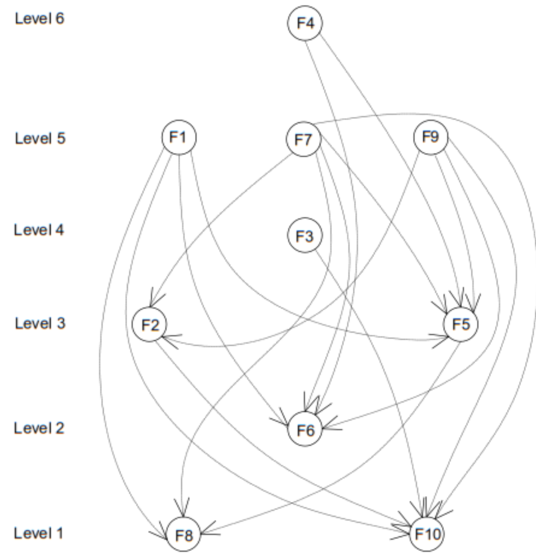

Fig. 2 Digraph : Significant Links in the Labour Productivity System

We can now represent the findings of the ISM analysis in a diagrammatic manner called a digraph. In the following Figure 1, we can see that there are direct links of factors from one level to another and Figure 2 shows other significant links which are inter-relating and linking between factors which are not in the precedent or succeeding level.

The next step in the process is to identify the characteristics of the various factors within the system. This is done by the use of MICMAC analysis. The Figure 3 represents the MICMAC analysis of the factors with the driving power of the factors on the abscissa and dependence power as the ordinate.

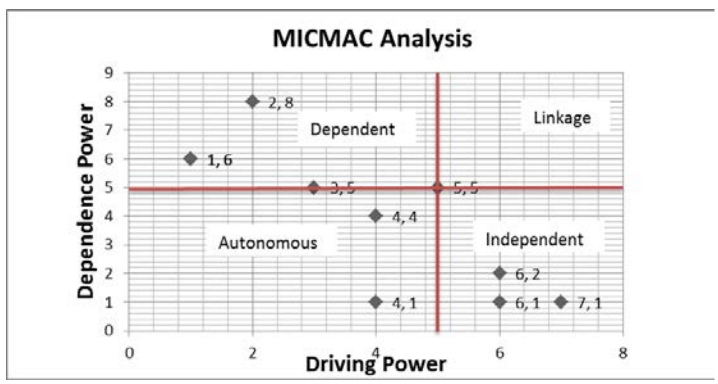

Fig. 3 MICMAC Analysis

6 OBSERVATIONS AND DISCUSSIONS

The analysis of the elements of the labour productivity system in the construction industry is summarized in Table 10.

TABLE 10
SUMMARY OF THE ANALYSIS

S. No	Factor	Factor No.	Level	Factor Type

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1	Insecure Feeling of labour	F8	1	Dependent
2	Labour inattentiveness	F10	1	Dependent
3	Method of working	F6	2	Dependent
4	Incentives and motivation	F2	3	Autonomous
5	Non planning of construction activities	F5	3	Dependent, autonomous
6	Communication between labour and supervisor	F3	4	Equally likely
7	Labour Experience	F1	5	Independent
8	Supervision	F7	5	Independent
9	Payment Delay	F9	5	Independent
10	Labour training	F4	6	Autonomous

From the Level Partition step we could observe the following. Labour Training (F4) is the factor occupying the most important position in the system as per the analysis with Level 6 and its characteristic being Autonomous. Labour Experience (F1), Supervision (F7), Payment delay (F9) are independent factors which have high driving power and low dependence power falls in the next level, i.e. Level 5. Communication between labour and supervisor (F3) is a factor that occupies level 4 and it shares all the characteristics of the system. Incentives and motivation (F2) and non-planning of activities (F5) are in level 3, method of working (F6) is in level 2. Finally, insecure feeling of labours and labour inattentiveness are at the lower most level which is Level 1.

Through MICMAC analysis we could say that the linkage factors, independent factors, autonomous factors and dependent factors are the most critical elements of the system in descending order. The linkage and independent have high driving powers such that by rectifying them, the productivity can be easily enhanced. In our case, the factors which fall under linkage category are none, but we have as many as 3 factors under independent category, namely, supervision, labour experience and payment delay; coincidentally, fall on the same level. Looking out for the next important factors which are autonomous are labour training, incentives and motivation, and non-planning of construction activities which are in Level 1 and Level 3 respectively. Hence, the labour training element gets more importance compared to the other factors.

The digraph shows the relationships of the factors. Among the identified key factors from the level partitioning and MICMAC analysis, the inter linkages are scarce. We see that Labour experience is influenced by labour training, which is an autonomous factor and occupies a high level in the system. The next most critical factors such as motivation to workers and non-planning of workers do not affect the independent factors of the system.

7 Conclusion

The paper discusses an efficient and simple methodology to approach a problem with systems thinking, Interpretive Structural Modeling (ISM) which establishes the interactions, interrelations and the inter dependencies of the elements identified in the system. Hence, systems approach can structuralize a mental model of an unorganized problem.

The ISM uses pair-wise comparison for giving the linkages between the various factors. The steps involved are forming a Structural Self Interaction Matrix, forming the Reachability Matrix, Level partitioning, Presentation through digraphs. A MICMAC analysis is done to obtain the characteristic of the factors based on their driving power and dependence power. Finally the rationale behind the linkages is observed for proposing an efficient counteracting measure.

In our case, among the factors discussed, labour experience, payment delay, supervision and labour training are found to be the most critical factors that have to be concentrated for proposing Labour Productivity enhancement measures.

In further studies, more number of elements of the labour system can be taken into consideration for analysis. Also, ISM results can be compared with other existing quantitative statistical factor analyzing methods.

Acknowledgment

We thank the field experts who helped us to identify and frame the contextual relations between the various factors influencing labour productivity.

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