



# Applying Total Interpretive Structural Modeling to Study Factors Affecting Construction Labour Productivity

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## Abstract

Construction sector has always been dependent on manpower with most of the activities being labour intensive. Project productivity, thus, depends directly on productivity of labour. Enhancing labour productivity would contribute to overall success of the project. In order to improve labour productivity, associated factors need due consideration. Total interpretive structural modeling (TISM) is implemented as a methodology for identifying and summarizing relationships among factors which affect productivity of labour. 10 most significant factors negatively affecting construction labour productivity are considered for developing model that establishes interpretive relationship among these factors. The result shows that material shortages, tool/equipment shortages, drawing & specification alterations during execution and working seven days per week without holiday have strong driving power and weak dependence power and are at the lowest level in hierarchy in the TISM model. Lack of labour surveillance and lack of labour experience have strong driving and strong dependence power. Top management of the project must stress on variables having high driving power so as to facilitate improvement in the overall productivity of construction site.

**Keywords:** Construction project, Labour productivity, Interpretive structural modeling, Total interpretive structural modeling

## Introduction

Construction industry is a labour oriented industry. Construction is a craft-based activity and the labour behaviour has a large influence upon the organization and overall performance of any construction firm. Construction projects are characterized by their uniqueness. They have long been considered to have the highest labour component in comparison to other industries (Choromokos J. Jr. and McKee K.E., 1981; Arditi, 1985; Thomas et al., 1990; Kaming et al., 1996; Moselhi O. and Khan Z., 2012). In most countries, labour cost comprises 30 to 50% of the overall project's cost, and thus is regarded as a true reflection of the economic success of the project (Jarkas A. and Bitar C., 2012).

Improving productivity is a major concern for any profit-oriented organization, as it represents the effective and efficient conversion of resources into marketable products and determines business profitability. For construction industry, productivity can be improved by improving the performance of major contributors i.e. labour. Labour performance depends upon number of parameters. The contractor, who supervises the performance of labourers, needs to understand the priority of these factors so as to minimize the delays and improve labour productivity

This paper discusses the nature of Total Interpretive Structural Modeling (TISM) as methodology for dealing with this complex issue. Aspects of managing complexity relating particularly to the use of TISM are explored. Use of TISM gives a systematic relation between the factors affecting labour productivity.

## **TISM Technique**

Origin of TISM is from Interpretive Structural Modeling (ISM) technique facilitating development of graphical representations of complex systems. Research related to ISM dates back to 1970s. It is a methodology which enables individuals to establish complex relationships between multiple elements in a complex situation (Warfield, 1974). ISM is an interactive learning process. 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 (Sage,1977). ISM is a tool which permits identification of structure within a system. The system may be technical, social, medical or any system which contains identifiable elements which are related to one another in some fashion (Farris & Sage ,1975).

Sushil (2012), Nasim (2011) have adopted a modified version of ISM called the TISM. The process of interpretive structural modeling has been revisited and upgraded to TISM. It incorporates the interpretation of each relation i.e. not only gives direct relation but also gives transitive relation. This is not only useful in making the structural model fully interpretive, but also contributes in creating a knowledge base of the interpretive logic of all the relations.

## **Use of ISM and TISM**

A study by Watson (1978) explains the rationale for the use of ISM in activities such as technology assessment and the basic concepts underlying the technique. ISM has been implemented to analyze factors contributing to vendor selection (Mandal & Deshmukh,1994), production planning (Haleem et al, 2012), supply chain management (Singh, 2011; Qureshi et al. 2008), quality management (Sahney, et al. 2010), six sigma (Soti et al., 2010), total quality management for airline performance (Singh & Sushil, 2012), exploring the involvement aspect of customers towards greening of the supply chain (Kumar et al. 2013).

TISM is an innovative version of Warfield's Interpretive Structural Modeling technique, and is used to model and structure the factors for greater understanding of the interplay of these factors (Sushil, 2005a, 2005b, 2012). TISM is used by Nasim, (2011) to model and structure the forces of change and continuity in e-government. Prasad & Suri, (2011) have applied TISM to model continuity and change forces in private higher technical education. In the study by Wasuja et al. (2012), TISM is used to create a hierarchy amongst the various factors of cognitive bias in selling specialty drugs and interpret the relationships amongst them. TISM has been used to model strategic performance factors for effective strategy execution (Srivastava & Sushil, 2013).

## **Labour Productivity**

Construction labour productivity is often influenced by variations in work conditions and management effectiveness. It is substantially important to understand the nature and extent to which individual parameters affect productivity (Moselhi & Khan, 2012). Many definitions of productivity exist depending on the purpose of the measurements. Productivity is the ratio of output to input. Hourly outputs are widely used to measure labour productivity in construction research (Sonmez & Rowings, 1998; Hanna et al. 2008). Compared with cost-based output measures (Eastman & Sacks, 2008), measurement by hourly output helps to avoid many external factors that cause cost variances, so hourly output is commonly recognized as a more reliable measurement of productivity for construction operational activities. Zhigang, et al, (2011) define construction labour productivity as the ratio between production output and labour hours consumed to deliver the corresponding output. Loss of productivity is experienced when a

contractor does not reach the planned rate of productivity (i.e., the contractor is expending more effort per unit of production than originally planned). The result is a loss of money for the contractor and a delayed and possibly more costly project for the owner. Therefore, an important, sometimes challenging aspect of construction cost control is measuring and tracking work hours and production in sufficient detail to allow analysis of the data. Without this level of data, it will be impossible to determine the true root cause(s) of any poor labour productivity and to take early remedial action to forestall further deterioration or restore it (Ibbs, 2012).

### Factor Identification

Among numerous parameters affecting construction labour productivity, some have long term effects whereas some may only influence productivity on short term or temporary basis. Some may not only have long term but may also have ripple effect (Moselhi & Khan., 2012). They can be broadly classified as (Shehata & El-Gohary, 2011) industry related factors, management related factors, and labour related factors. A total of 45 factors influencing construction productivity are identified out of which 10 major factors are selected on the basis of work carried out, careful review of literature and suggestions from local experts in building construction by Enshassi et al. (2007). The present study makes use of these factors to analyze their interrelationships using TISM. These factors negatively affect labour productivity and they are material shortages, lack of labour experiences, lack of labour surveillance, misunderstanding between labour and superintendents, drawings and specification alteration during execution, payment delay, labour disloyalty, inspection delay, working seven days per week without holiday, tool/ equipment shortages.

### Research Methodology

The article explores interrelation of the 10 selected factors affecting labour productivity. The total interpretive structural modeling has been used to interpret the linkages using the tool of interpretive matrix. The methodology involves taking the responses of field experts. A group discussion and interviews of experts from construction industry helps to establish the contextual relationships among these factors necessary for building the interpretive model. Judgmental sampling has been used to select the experts. The selected experts include construction firm owners, contractors and academicians from India. The data from discussions has been used to represent the contextual relationships in structural self-interaction matrix which is further processed to differentiate the identified variables.

### Application of TISM

Since the factors under consideration negatively affect labour productivity, it is ideal to reduce their occurrence and effect during the project. All of these factors cannot be given same amount of attention by the management since it is practically not feasible. Efforts in reducing their effect or occurrence at the root level itself thus have to be carefully managed. This can be achieved by finding relationship of these variables with one another and with overall labour productivity to optimize efforts; the factors should be ranked based on their overall effect on labour productivity. This can be achieved by systematic interpretive logic represented by TISM.

TISM starts with an identification of variables, which are relevant to the problem or issue, and then extends with a group problem solving technique. Then a contextually relevant subordinate relation is chosen. Having decided on the element set and the contextual relation, a structural self-interaction matrix is developed based on pair wise comparison of variables. In the next step, the SSIM is converted into a reachability matrix and its transitivity is checked. Once transitivity embedding is complete, a matrix model is obtained. Then, the partitioning of the elements and an extraction of the structural model called ISM is derived (Attri et al. 2013).

### Structural Self Interaction Matrix (SSIM)

The variables are identified as V1 to V10 in the given sequence for simplifying further study. A matrix given below helps establish relation between row variable *i* and column variable *j*. The existence of a relation between any two variables and the associated direction of relation is asked to a group of experts. Four symbols V, A, O and X are used for the type of relation existing between the two variables under consideration. The symbols are:

- i. V- When *i* leads to *j* but *j* does not lead to *i*;
- ii. A- When *j* leads to *i* but *i* does not lead to *j*;
- iii. X- When *i* leads to *j* and *j* leads to *i*;
- iv. O- When the relation between the elements does not appear valid.

The structural self-interaction matrix (SSIM) for the element under consideration is then prepared by filling in the responses of the group on each pair-wise interaction between the elements (Sushil, 2012) as shown in Table 1 below.

Code	Variable	V10	V9	V8	V7	V6	V5	V4	V3	V2	V1
V1	Materials shortages	X	X	V	O	V	V	V	O	O	-
V2	Lack of labour experiences	A	O	V	V	O	O	V	A	-	
V3	Lack of labour surveillance	O	A	O	V	O	O	V	-		
V4	Misunderstanding between labour & superintendents	O	A	O	X	X	A	-			
V5	Drawings & specification alteration during execution	X	V	V	O	V	-				
V6	Payment delay	A	O	A	X	-					
V7	Labour disloyalty	O	A	A	-						
V8	Inspection delay	A	O	-							
V9	Working seven days per week without holiday	A	-								
V10	Tool / equipment shortages	-									

Table 1 Structural self interaction matrix

### Reachability Matrix (RM)

RM is prepared from SSIM by transforming the information in each entry of the SSIM into 1's and 0's in the reachability matrix. This transformation is based on the relation given in Table 2. RM thus prepared is given in Table 3 below. Entry for a variable with itself is represented by 1.

(i-j) Entry	(i to j) Relation	(j to i) Relation
V	1	0
A	0	1
X	1	1
O	0	0

Table 2 Rule for transforming SSIM to RM

Variable Code	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
V1	1	0	0	1	1	1	0	1	1	1
V2	0	1	0	1	0	0	1	1	0	0
V3	0	1	1	1	0	0	1	0	0	0
V4	0	0	0	1	0	1	1	0	0	0
V5	0	0	0	1	1	1	0	1	1	1
V6	0	0	0	1	0	1	1	0	0	0
V7	0	0	0	1	0	1	1	0	0	0
V8	0	0	0	0	0	1	1	1	0	0
V9	1	0	1	1	0	0	1	0	1	0
V10	1	1	0	0	1	1	0	1	1	1

Table 3 Reachability matrix

### Partitioning the Reachability Matrix Into Different Levels

The level partition is carried out to know the position of variables level-wise. Reachability set for a variable represents variables that carry value 1 in row of that variable. Similarly, antecedent set for a variable represents variables that carry value 1 in column of that variable. Intersection of the reachability set and the antecedent set will be the same as the reachability set if the element is at the top level. The top level elements satisfying the above condition should be removed from the element set and the exercise is to be repeated iteratively till all the levels are determined (Sushil, 2012). Table 4 shows the iterations and Table 5 gives levels of all the variables obtained from iterations.

Variable	Reachability Set (RS)	Antecedent Set (AS)	AS ∩ RS	Level
<b>Iteration 1</b>				
V1	1,4,5,6,8,9,10	1,9,10	1,9,10	
V2	2,4,7,8	2,3,10	2	
V3	2,3,4,7	3,9	3	
<b>V4</b>	<b>4,6,7</b>	<b>1,2,3,4,5,6,7,9</b>	<b>4,6,7</b>	<b>I</b>
V5	4,5,6,8,9,10	1,5,10	5,10	
<b>V6</b>	<b>4,6,7</b>	<b>1,4,5,6,7,8</b>	<b>4,6,7</b>	<b>I</b>
<b>V7</b>	<b>4,6,7</b>	<b>2,3,4,6,7,8,9</b>	<b>4,6,7</b>	<b>I</b>
V8	6,7,8	1,2,5,8,10	8	
V9	1,3,4,7,9	1,5,9,10	1,9	
V10	1,2,5,6,8,9,10	1,5,10	1,5,10	
<b>Iteration 2</b>				
V1	1,5,8,9,10	1,9,10	1,9,10	
V2	2,8	2,3,10	2	
V3	2,3	3,9	3	
V5	5,8,9,10	1,5,10	5,10	
<b>V8</b>	<b>8</b>	<b>1,2,5,8,10</b>	<b>8</b>	<b>II</b>
V9	1,3,9	1,5,9,10	1,9	
V10	1,2,5,8,9,10	1,5,10	1,5,10	

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<b>Iteration 3</b>				
V1	1,5,9,10	1,9,10	1,9,10	
<b>V2</b>	<b>2</b>	<b>2,3,10</b>	<b>2</b>	<b>III</b>
V3	2,3	3,9	3	
V5	5,9,10	1,5,10	5,10	
V9	1,3,9	1,5,9,10	1,9	
V10	1,2,5,9,10	1,5,10	1,5,10	
<b>Iteration 4</b>				
V1	1,5,9,10	1,9,10	1,9,10	
<b>V3</b>	<b>3</b>	<b>3,9</b>	<b>3</b>	<b>IV</b>
V5	5,9,10	1,5,10	5,10	
V9	1,3,9	1,5,9,10	1,9	
V10	1,5,9,10	1,5,10	1,5,10	
<b>Iteration 5</b>				
V1	1,5,9,10	1,9,10	1,9,10	
V5	5,9,10	1,5,10	5,10	
<b>V9</b>	<b>1,9</b>	<b>1,5,9,10</b>	<b>1,9</b>	<b>V</b>
V10	1,5,9,10	1,5,10	1,5,10	
<b>Iteration 6</b>				
V1	1,5,10	1,10	1,10	
<b>V5</b>	<b>5,10</b>	<b>1,5,10</b>	<b>5,10</b>	<b>VI</b>
<b>V10</b>	<b>1,5,10</b>	<b>1,5,10</b>	<b>1,5,10</b>	<b>VI</b>
<b>Iteration 7</b>				
<b>V1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>VII</b>

Table 4 Level partition of variables

Sr.No.	Variable	Code	Level in TISM
1	Misunderstanding between labour and superintendents	V4	I
2	Payment delay	V6	I
3	Labour disloyalty	V7	I
4	Inspection delay	V8	II
5	Lack of labour experiences	V2	III
6	Lack of labour surveillance	V3	IV
7	Working seven days per week without holiday	V9	V
8	Drawings and specification alteration during execution	V5	VI
9	Tool / equipment shortages	V10	VI
10	Materials shortages	V1	VII

Table 5 Variable and respective level

### Diagraph with Significant Transitive Links

The elements are arranged graphically in levels and the directed and significant links are shown as per the relationships observed in the reachability matrix. Figure 1 below gives the diagrammatic representation of total interpretive model obtained from the study.

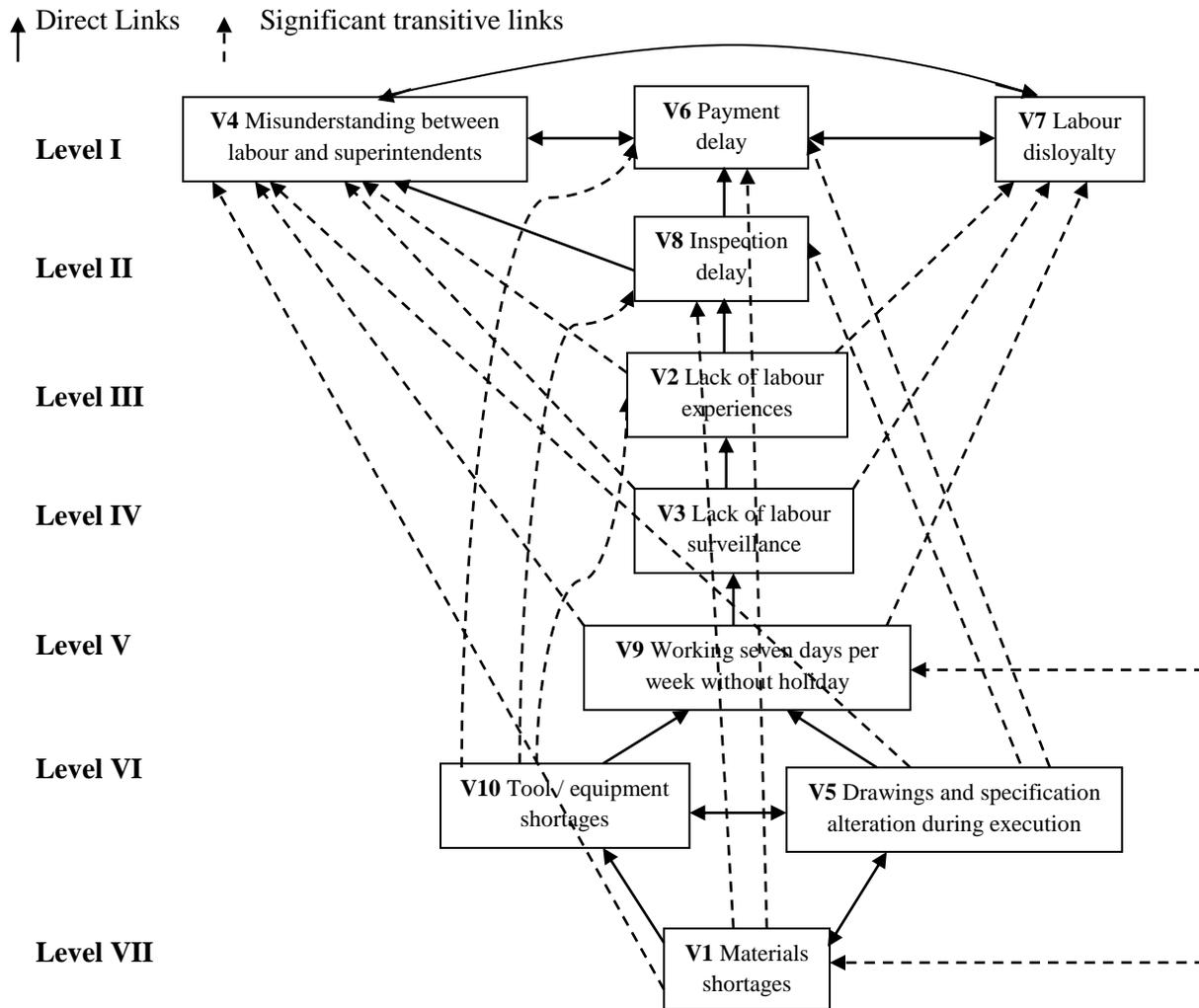


Figure 1 Diagraph for factors affecting construction labour productivity using TISM

### Observations and Discussion

Interaction matrix represents the diagraph in matrix format. It shows direct and significant links of a factor with all other factors at a glance. Table 6 gives interaction matrix showing relation between the variables, direct link represented by<sup>a</sup> and significant transitive link represented by<sup>b</sup>.

Variable	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
V1	-	0	0	1 <sup>b</sup>	1 <sup>a</sup>	1 <sup>b</sup>	0	1 <sup>b</sup>	1 <sup>b</sup>	1 <sup>a</sup>
V2	0	-	0	1 <sup>b</sup>	0	0	1 <sup>b</sup>	1 <sup>a</sup>	0	0
V3	0	1 <sup>a</sup>	-	1 <sup>b</sup>	0	0	1 <sup>b</sup>	0	0	0
V4	0	0	0	-	0	1 <sup>a</sup>	1 <sup>a</sup>	0	0	0
V5	0	0	0	1 <sup>b</sup>	-	1 <sup>b</sup>	0	1 <sup>b</sup>	1 <sup>a</sup>	1 <sup>a</sup>
V6	0	0	0	1 <sup>a</sup>	0	-	1 <sup>a</sup>	0	0	0
V7	0	0	0	1 <sup>a</sup>	0	1 <sup>a</sup>	-	0	0	0
V8	0	0	0	0	0	1 <sup>a</sup>	1 <sup>a</sup>	-	0	0
V9	1 <sup>b</sup>	0	1 <sup>a</sup>	1 <sup>b</sup>	0	0	1 <sup>b</sup>	0	-	0
V10	1 <sup>a</sup>	1 <sup>b</sup>	0	0	1 <sup>a</sup>	1 <sup>b</sup>	0	1 <sup>b</sup>	1 <sup>a</sup>	-

<sup>a</sup>- Direct link <sup>b</sup>- Significant link

Table 6 Interaction matrix

Figure 2 gives the driving power and dependence power of selected factors as obtained from the model. Quadrant I represents autonomous variables, quadrant II represents dependent variables, quadrant III represents linkage variables and quadrant IV represents independent (driver) variables.

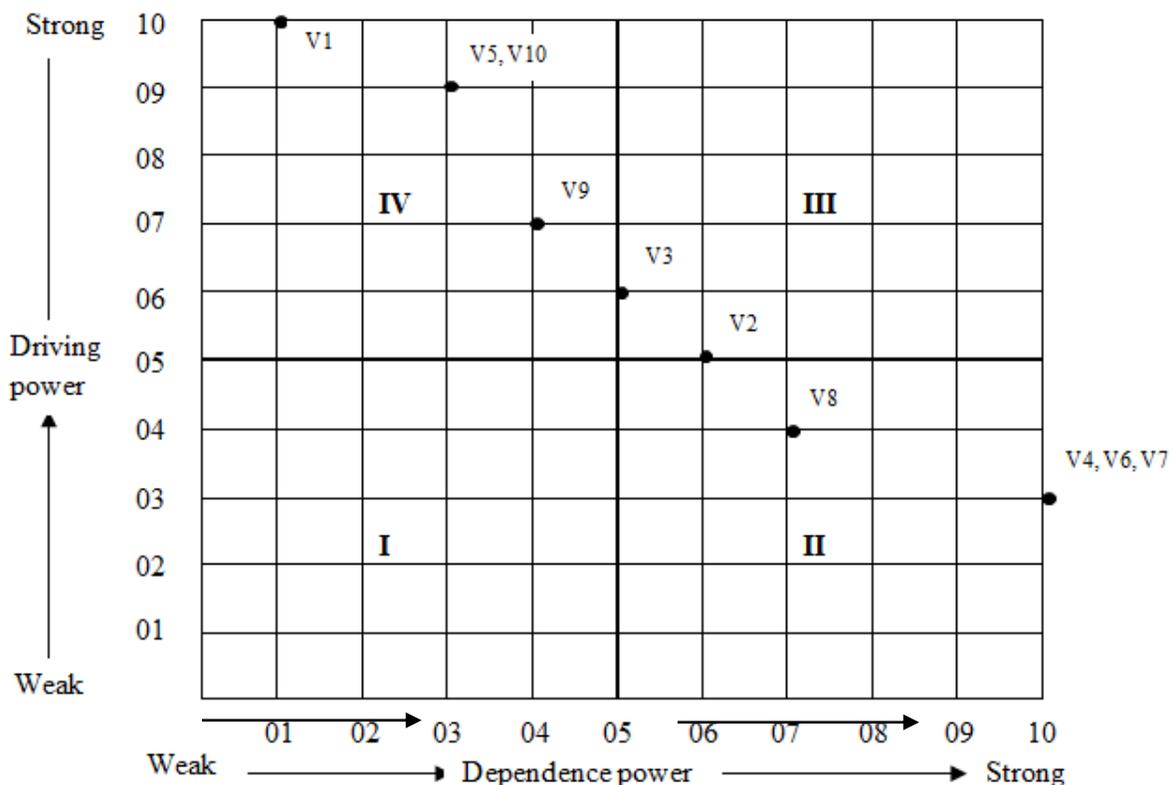


Figure 2: Driving power and dependence diagram

Material shortages (V1), drawings and specification alteration during execution (V5), tool/equipment shortage (V10), working seven days per week without holiday (V9) lie in the IV<sup>th</sup>

quadrant representing independent variables that have strong driving and weak dependence power. III<sup>rd</sup> quadrant represents group of linkage variables that have strong driving and strong dependence power. These variables are relatively unstable and any actions on these have an effect on others and on themselves also. Managers must take special care in managing these variables. V3 i.e. lack of labour surveillance lies on border line of quadrant III & IV and V2 i.e. lack of labour lies on border line of quadrant III & II. Inspection delay (V8), misunderstanding between labour and superintendants (V4), payment delay (V6) and labour disloyalty (V7) fall in the II<sup>nd</sup> quadrant representing dependent variables having weak driving and strong dependence power and lie above the middle portion of TISM hierarchy.

Following are a few suggestions to avoid the ill effects of occurrence of the factors affecting labour productivity. Since material shortages has been observed to have the highest driving power and low dependence power, the contractor or the client (if provides material) should arrange for timely materials supply and should possess minimum safety stock. As far as possible, drawing and specifications should be finalized by all the parties to the contract including the contractor to minimize variations. Adequate tools and appropriate equipment should be made available as per the requirement of the project schedule. To reduce work fatigue, staff should be given a holiday at regular intervals. Two important factors falling in the middle of the hierarchy are lack of labour surveillance, lack of labour experience. Sufficient labour supervision helps to track the performance of labour and hence the progress of project. Experienced labour would execute a task in lesser duration and with more efficiency as compared to an inexperienced labour. The contractor shall set a minimum standard of experience in years along with the requisite set of skills. If the inspection is delayed, the labour tends to slow down the progress, hence should be avoided. Labour disloyalty, payment delay and misunderstanding between labour and superintendants are direct labour related factors which can be avoided by the contractor or client. It is observed that the base variables of the diagraph are related to organisational management whereas the top variables are direct labour related. This shows that problems and issues at organisational level affect the labour behaviour and productivity.

## Conclusion

Labour productivity has been a matter of very high importance in construction industry. Application of TISM to better understand the factors contributing to labour productivity provides an intellectual way to analyze the situation and plan the corrective actions to improve upon overall performance of the construction site. Based on the model obtained from the study, the contractors should give more importance variables with high driving power to avoid the effect of dependent variables which have less significance. The contractor, based on this chart, could analyze the construction site and find the root cause of lesser productivity and take measures accordingly. The limitation of the study is since only 10 variables are considered; the model may not be applicable to scenarios where factors other than these are more significant. Further research can be carried out to statistically validate the model with the help of structural equation modeling. Also, TISM approach can be implemented to areas where number of attributes contribute towards a problem.

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**Annexure**

**Interpretive logic**

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
V1	-	-	-	-	Material shortages would affect process on site and may lead to on the spot variations.	-	-	-	Shortages in initial stages would lead to working w/o holidays in later stages.	Material shortage and tool/equipment shortage are correlated.
V2	-	-	-	Ill experience labour is prone to creating misunderstandings.	-	-	Ill experience labour would be more prone to be disloyal.	Inspection would be delayed if ill experienced labour takes more time in performing a task.	-	-
V3	-	Lack of watch on labours may affect quality of labour.	-	-	-	-	-	-	-	-
V4	-	-	-	-	-	Misunderstandings may lead to delay in payments.	Misunderstandings may increase disloyalty among the labours.	-	-	-
V5	-	-	-	-	-	-	-	-	Change in specifications may require w/o holiday working.	On spot variations may bring in tools/ equipment shortage.
V6	-	-	-	Holding up the payments may lead to misunderstandings.	-	-	Delay in payment leads to disloyal labour.	-	-	-
V7	-	-	-	A disloyal labour may create misunderstandings.	-	A disloyal labour if pointed by the higher ups may get delayed payments.	-	-	-	-
V8	-	-	-	-	-	Inspection delay may lead to delay in final payment.	Delay in inspection may cause labour disloyalty.	-	-	-
V9	Working continuously may lead to material shortage.	-	Working endlessly would reduce the tendency of keeping proper watch on labours.	-	-	-	-	-	-	-
V10	Material shortage and equipment shortage are correlated.	-	-	-	Shortage of tools may lead to variations and vice versa.	-	-	-	Tool shortage may lead to w/o holiday working in later stages of project.	-