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A METHODOLOGY FOR PROSPECTIVE OPERATIONAL DESIGN CO-ORDINATION

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Abstract

Engineering companies are continually faced with the challenge of how best to utilise their design team given some design project. Decisions regarding how to distribute the project work load amongst the members of the design team are the responsibility of a project manager who, in order to do this, often relies upon previous experience and/or the support of some planning tool. Furthermore, a project manager rarely has the opportunity to assess the capability of the design team against the current work load in order to determine what, if any, alterations could be made to the team to facilitate appropriate reductions in project time and cost.

This paper proposes a mathematical-based methodology aimed at identifying shortfalls in design teams, which if remedied would result in a more efficient project in terms of time and cost. The methodology provides a means of identifying those skills within the design team, with respect to the outstanding work load, in which improvements would have the greatest influence on reducing time and cost. In addition, the methodology employs a genetic algorithm for the purpose of scheduling tasks to be undertaken by potential design teams.

The methodology is applied to two practical case studies provided by engineering industry. The first case study involves the assessment of a multi-disciplined design team consisting of single-skilled engineers. In contrast, the second case study entails the assessment of multi-skilled engineers within a multi-disciplined design team. As a result of applying the methodology to the case studies, potential improvement to the design teams are identified and, subsequently, evaluated by observing their effects.

Keywords: Design management, design teams

1 Introduction

Operational design co-ordination in real-time is regarded as a means of improving the performance of the design development process [1]. Such co-ordination can be viewed as the coherent and dynamic management of tasks, resources and schedules, in addition to unexpected events that occur during the design development process. As a result of the research conducted in the area of real-time operational design co-ordination [2], an extension of the work is aimed at identifying how further potential improvements could be made in terms of the performance of the design development process.

The management of resources is an integral part of any approach to engineering design management. Indeed, it has been indicated that the optimal performance of a product's design and development process can be realised by maximising the utilisation of the available talents/ resources [3]. Similarly, in relation to design co-ordination, resource management has been identified as continuously creating the opportunity for the optimised allocation and utilisation of resources [2]. In order to make the *best* use of resources they need to be appropriately assigned to the tasks to be undertaken. Indeed, the assignment of tasks to individuals or groups, i.e. scheduling, has been viewed as one of the fundamental components of co-ordination [4-7].

In light of the significance of resource management, one means of further improving the performance of the design development process lies in hypothesising and evaluating realistic alterations in the existing design team, with respect to the work outstanding. Prospective operational design co-ordination entails *what-if* analyses being conducted, which includes assessing schedules that correspond with considered changes to the design team. Such changes are identified by establishing where investment in new engineers or development of existing engineers would result in a more balanced design team and offer the most significant benefits in terms of time and cost. The use of time as the primary factor is widely acknowledged. For example, it has been indicated that the time taken to get a new product to market is the primary focus of contemporary strategies aimed at gaining competitive advantage [8]. Similarly, as a result of intense competition in the marketplace, it has been stated that “time is recognised as the most important of the three cardinal variables in projects: time, cost and quality” [9].

Section 2 presents an overview of the methodology for prospective operational design co-ordination. Section 3 summarises the application of the methodology to two industrial case studies. In Section 4, the results of the case studies are discussed. Finally, concluding remarks are given in Section 5.

2 Methodology

The aim of the methodology for prospective operational design co-ordination is to derive an improved design team that redresses any imbalance in the original design team with regard to the tasks to be undertaken. Consequently, reductions can be achieved in the time taken to complete the process and cost of utilising the design team. The significance of redressing an imbalance in a design team, given a particular work load, is that it enables an appropriate trade-off to be reached in terms of the time and cost of the design programme.

An overview of the methodology is shown in Figure 1.

Initially, a genetic algorithm [10] is used to derive a schedule based on knowledge of the existing design team and outstanding tasks. The schedule derived is then assessed such that deficiencies in the design team can be identified. This assessment involves determining work-to-skill ratios, which provide an indication of the duration of the tasks associated with each discipline per unit of the design team’s skill in that discipline. Based on the deficiencies in the design team, support is proposed in the form of simulated design teams. These simulated design teams are then considered with the outstanding tasks in order to derive corresponding off-line, i.e. not to be used, schedules. The process of identifying deficiencies and proposing support is repeated until an improved, i.e. more balanced, design team is derived, which, if realised, would result in appropriate reductions in time and cost to complete the outstanding tasks.

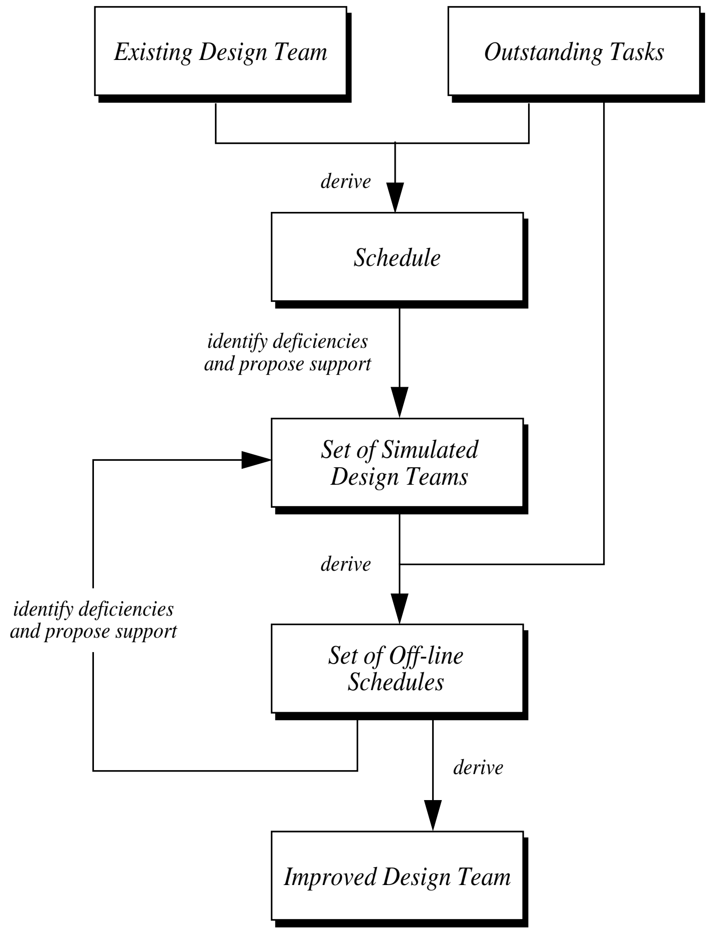

Figure 1. An overview of the methodology

3 Industrial case studies

Practical case studies have been provided by two companies to enable the application of the methodology.

Armstrong Technology Associates provide a marine design and engineering consultancy service, which can undertake the design, engineering analysis and production definition of all types of ships and floating structures for the offshore industry. The case study provided is concerned with the design programme of the conversion of a Lighter Aboard SHip (LASH) carrier, i.e. barge carrier, to a multi-role offshore support vessel.

domnick hunter limited is an international group of companies involved in the development and provision of filtration, purification and separation products for various industries and applications. The case study provided by the research and development department involves the design development phase of compressed air treatment equipment.

Two case studies are used to demonstrate the application of the methodology as the design teams are modelled differently in each case. With respect to Armstrong Technology Associates, single-skilled engineers work within a multi-disciplinary design team. In contrast, domnick hunter limited employs multi-skilled engineers within a multi-disciplinary design team.

3.1 Marine vessel conversion design programme

A schedule is produced using a genetic algorithm, and knowledge of (i) the tasks within the design programme, and (ii) engineers within the design team. More specifically, task knowledge comprises of the datum durations of each task and the dependencies between them. Knowledge of the engineers consists of a skill coefficient that corresponds with their respective designations, i.e. consultant, senior design engineer and design engineer. A skill coefficient is an indication of the capability of an engineer with respect to undertaking tasks within a particular discipline. In addition, skill coefficients range from 0 to 1. A skill coefficient of 0 signifies that an engineer cannot undertake tasks associated with a particular discipline. Conversely, a skill coefficient of 1 denotes than an engineer is completely proficient in terms of undertaking tasks within a particular discipline. Cost per unit time of each engineer was also assigned in accordance with their respective designations.

As shown in Table 1, the design programme involved 132 tasks within three disciplines.

Table 1. Design programme: task composition

Discipline	Number of Tasks
Naval Architecture	86
Marine Engineering	22
Electrical Engineering	24

Consultation with the Senior Project Manager resulted in skill coefficients being provided for each engineer to be utilised on the design programme. Since engineers are single-skilled, they are assigned one skill coefficient for their respective discipline in accordance with their designation, as shown in Table 2.

Table 2. Composition of the design team

Discipline	Team Member Designation	Number of Engineers	Skill Coefficient	Cost per unit Time
Naval Architecture	Consultant	2	1.0	10.0
	Senior Design Engineer	4	0.8	8.5
	Design Engineer	2	0.6	7.0
Marine Engineering	Consultant	2	1.0	10.0
	Senior Design Engineer	1	0.8	8.5
	Design Engineer	2	0.6	7.0
Electrical Engineering	Senior Design Engineer	2	0.8	8.5
	Design Engineer	1	0.6	7.0

As mentioned previously, based on knowledge of the tasks and engineers summarised in Tables 1 and 2 respectively, a genetic algorithm was used to create a datum schedule, which was minimised in terms of time and cost. For the design programme, the time and cost associated with the datum schedule was 59.5 weeks and 175222 units respectively.

From the datum schedule derived, the estimated duration of all 132 tasks was determined. This involved dividing the datum duration of each task by the skill coefficient of the engineer to whom it was assigned. Work-to-skill ratios were then determined for each discipline by dividing the cumulative estimated duration of the tasks associated with the discipline by that cumulative skill coefficient of the engineers assigned these tasks. The ratios provided a measure of the duration of tasks associated with each discipline per unit of allocated skill coefficient. As such, a relatively high ratio indicates a deficiency in the corresponding discipline of the design team. In practice, for the datum case (shown in shaded cells) in Table 3, the ratios calculated for each discipline revealed that electrical engineering was deficient in terms of the engineers utilised in the derived schedule. Furthermore, ratios for naval architects and marine engineers were observed as being of the same order.

With regard to proposing support in the form of simulated design teams, the addition of one electrical engineer in each of the three designations at a time was suggested (cases 1 to 3 in Table 3), i.e. consultant, senior design engineer, and design engineer. Since these additions did not result in the imbalance in work-to-skill ratio being redressed between all disciplines, further simulated design teams were considered. These teams involved the addition of two electrical engineers in each possible combination of the three designations mentioned, as summarised in cases 4 to 9 of Table 3.

Table 3. Simulated design team augmentations and work-to-skill ratios

Case	**Electrical Engineering**			**Work-to-Skill Ratio**		
	Design Engineer	**Senior Design Engineer**	**Consultant**	**Naval Architects**	**Marine Engineers**	**Electrical Engineers**
Datum	Original Design Team			34.6	29.5	78.5
1	1	0	0	35.7	29.7	65.0
2	0	1	0	35.5	29.6	55.7
3	0	0	1	35.5	28.5	49.0
4	2	0	0	35.5	29.5	53.5
5	1	1	0	35.8	29.3	48.4
6	1	0	1	35.3	29.4	43.5
7	0	2	0	35.2	29.1	43.4
8	0	1	1	35.2	28.7	39.3
9	0	0	2	35.6	29.8	35.8

For each case outlined in Table 3, the effect on time and cost of the design programme when scheduled is shown in Figure 2. Also, in Figure 2, the datum case is denoted by the letter *D* and all other cases are signified by their respective case number

In relation to cases 1 to 3, Figure 2 indicates the greatest reduction in time and cost corresponds with the addition of a consultant electrical engineer to the original design team. Furthermore, in comparison with the datum case, the reduction in time and cost is approximately 22% and 1% respectively. Furthermore, with regard to cases 4 to 9, the addition of two electrical engineers in the various combinations of designation can be seen to predominantly result in further reductions in the estimated time to complete the schedule. In particular, the addition of two consultant electrical engineers, i.e. case 9, offers the greatest reduction in time of 28% with an associated 1% reduction in cost. As such, in relation to the design programme, the addition of two consultant electrical engineers causes the skill-to-work ratio of the three disciplines to be approximately equal leading to the conclusion that the imbalance within the design team has been redressed.

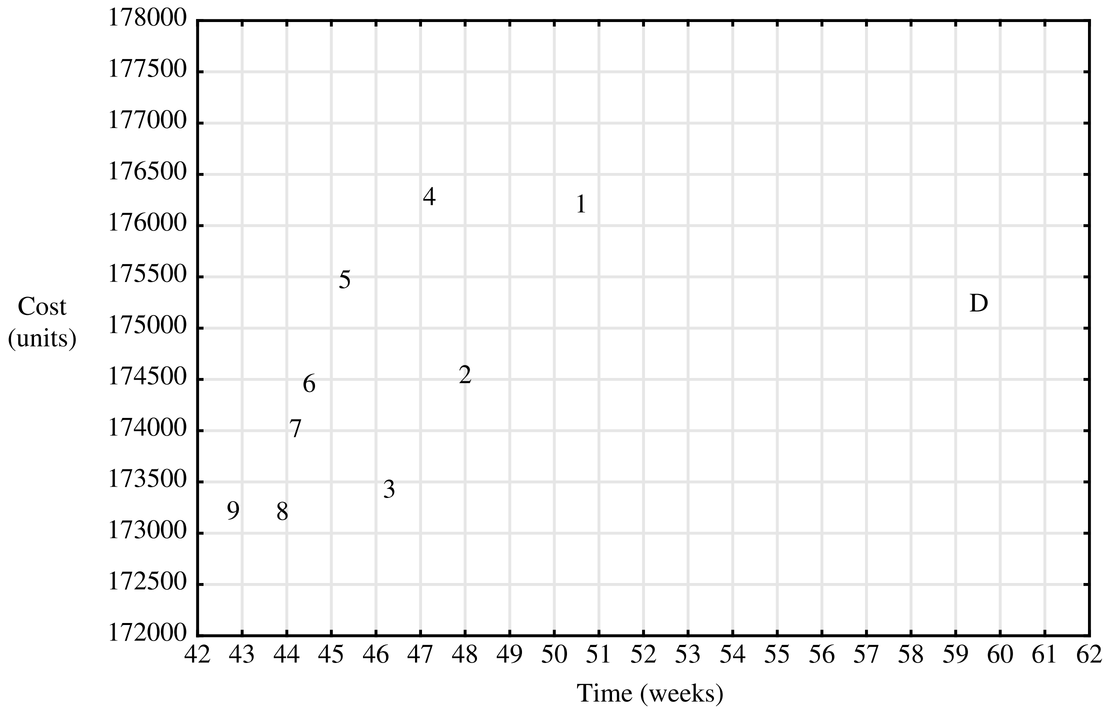

Figure 2. Scheduled design programme: cost versus time

3.2 Compressed air treatment equipment design development phase

As in the previous case study, knowledge of the tasks within the design development phase and the engineers in the design team was provided by the company. Specifically, 15 disciplines consisting of 190 tasks were involved in the design development phase of compressed air treatment equipment. Due to the multi-skilled, multi-disciplinary nature of the design team, each engineer was assigned a skill coefficient for each discipline in which they are capable of undertaking tasks, as shown in Table 4. These skill coefficients were determined by the Research and Development Manager based on experience of similar design development tasks that had been undertaken previously by the engineers within the design team.

Table 4. Design team: skill coefficients

Engineers (E1 to E9)	Skill Coefficients within Disciplines (D1 to D15)															Cost per unit Time
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	
E1	0.3	0	0	0	0	0	0	0.2	0.4	0	0.1	0	0.5	0.1	0.6	12
E2	0.9	0.1	0.1	0.1	0.5	0.5	0.5	0.2	0.1	0	0	0.9	0	0.1	0.1	20
E3	0.7	0.1	0	0	0.8	0.5	0.5	0.2	0.7	0.8	0	0	0.7	0.1	0.7	20
E4	0.5	0.9	0.9	0.9	0.1	0.5	0.3	0.7	0.5	0.6	0.8	0	0.5	0.8	0.2	15
E5	0.7	1.0	0.9	0.9	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0	0.5	0.8	0.2	17
E6	0	0	0	0	0	0	0	0	0	0	0	1.0	0	0	0	10
E7	0.5	0.1	0	0	0	0.3	0.2	0.5	0.8	0.9	0	0	0.9	0.1	0.9	17
E8	0	0	0	0.3	0.3	0	0.2	0.3	0	0	0	0	0	0	0	12
E9	0.5	0.1	0	0	0	0	0.3	0	0	0	0	0	0	0	0	17

In Table 4, the shaded cells denote those engineers able to undertake tasks associated with the corresponding discipline. Conversely, cells that are not shaded represent engineers that are unable to undertake tasks within the corresponding discipline. For example, engineer E3 has a skill coefficient of 0.7 with regard to all tasks within discipline D9. However, the same engineer is unable to undertake tasks associated with discipline D3 since his/her corresponding skill coefficient is zero.

In this case study, four iterations of the methodology were performed. Furthermore, each iteration of the methodology was based on the evaluation of the previous iteration. The simulated design teams are summarised in Table 5.

Table 5. Summary of simulated design teams

Iteration	**Case**	**Description**
-	Datum	Original design team.
1	1 - 7	Addition of engineers in disciplines D2, D8, D12.
2	8 - 13	Nullification of skill coefficients of 0.1, 0.1-0.2, 0.1-0.3,..., 0.1-0.6.
3	14 - 16	Addition of engineers in disciplines D8 and D12.
4	17 - 19	Increase skill coefficient for under-utilised engineers E1 and E9 in disciplines D8 and D12.

In cases 1 to 7, the addition of engineers to the design team in various combinations were considered in three disciplines. As shown in Figure 3, for these seven cases, the effect on time and cost of the design development phase was negligible and, as such, these additions of engineers were disregarded. Subsequently, alternative simulated design teams were considered involving the nullification of low values of skill coefficient, i.e. cases 8 to 13. That is, the engineers were not removed, rather their low values of skill coefficient were set to zero such that they would not be considered for being scheduled tasks associated with the corresponding discipline. As a result, it was found that engineers with skill coefficients lower than 0.3 should not be considered for tasks associated with the corresponding discipline as this caused increases in time and cost to complete the design development phase. Next, with skill coefficients of less than 0.3 nullified, for two disciplines, the addition of engineers and increasing skill coefficients of under-utilised engineers were considered.

Figure 3 shows the effect on time and cost of the design development phase for each of the cases outlined in Table 5. As in the previous case study, in Figure 3, the datum case is denoted by the letter *D* and all other cases are signified by their respective case number.

In Figure 3, the development of engineers (cases 17 to 19), with skill coefficients of less than 0.3 nullified, has resulted in the greatest reductions in time and cost. The lowest expected time to complete the design development phase corresponds with case 19, which involves increasing the skill coefficients of existing engineers (through appropriate training and development) in certain disciplines and nullifying skill coefficients less than 0.3 for all engineers. Specifically, case 19 corresponds to a 52% reduction in time and 45% reduction in cost. In addition, for case 19, the differences in work-to-skill ratios for the disciplines was shown to be significantly diminished. Thus, it was concluded that the imbalance within the design team had been largely redressed.

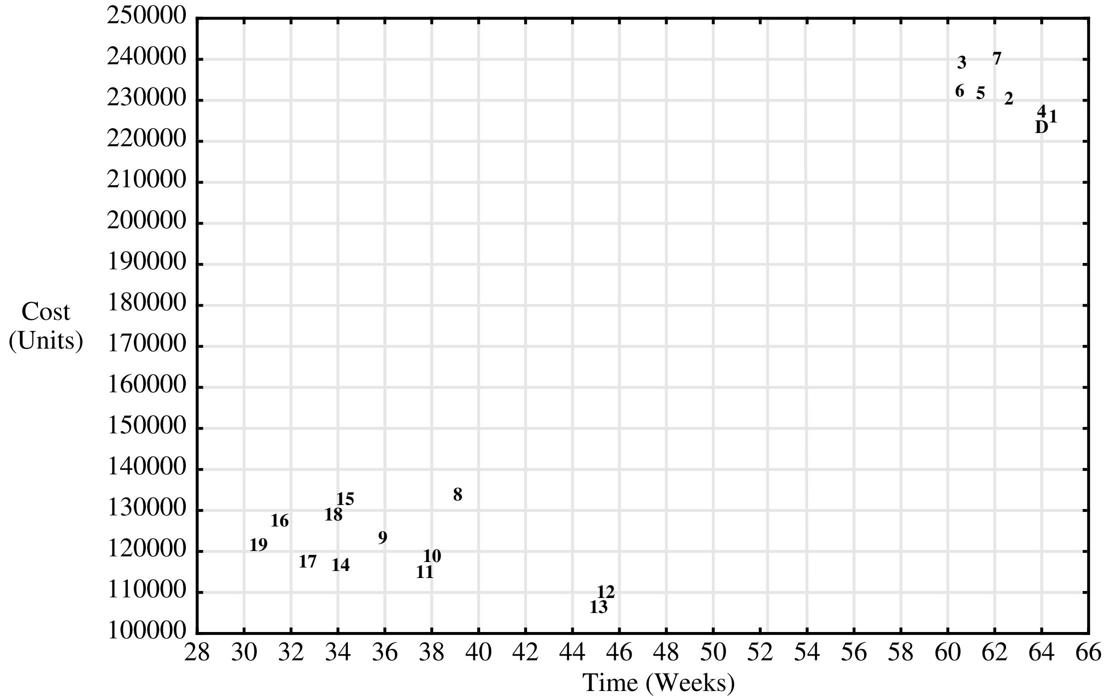

Figure 3. Scheduled design development phase: cost versus time

4 Discussion

4.1 Marine vessel conversion design programme

Applying the methodology to the marine vessel conversion design programme provided the company with the knowledge that an additional two consultant electrical engineers would potentially lead to a 28% time reduction in the design programme with no cost penalty being incurred in terms of utilising the engineers. Indeed, the cost of the design programme attributed to the utilisation of the design team would be marginally reduced, i.e. approximately 1%. Furthermore, the realisation of these time and cost benefits can be achieved by implementing the schedule derived using the genetic algorithm.

With regard to the recommendation to add two consultant electrical engineers to the design team, the company stated that "the findings of the case study are in agreement with the final allocation of resources as implemented in practice" and, furthermore, "this finding corroborates with our decision to allocate two additional electrical engineers to the design programme" [2]. Also, in relation to the decision made by the company, it was said that "the decision was determined during the design programme rather than at the outset as would have been indicated had we applied your methodology".

4.2 Compressed air treatment equipment design development phase

The application of the methodology to this case study enabled the company to determine the most appropriate modelling of their multi-skilled, multi-disciplinary design team. As a result of disregarding particular low skill coefficients of all engineers, and developing existing engineers with regard to their ability to undertake tasks associated with two particular disciplines, it has been shown that the estimated time and cost to complete the design development phase would potentially be reduced by 52% and 45% respectively.

From the correspondence provided by the company [2], it was stated that "the work provides a very useful technique for assessing our personnel requirements prior to starting the design development phase involving our multi-disciplinary, multi-skilled design team". Further, it was indicated that the non-trivial and complex nature of managing the design development phase was emphasised since, in contrast to the traditional project management technique of adding extra personnel, the findings of applying the methodology advised that the solution was to model people's capabilities more appropriately and then develop them.

5 Concluding remarks

The methodology for prospective operational design co-ordination facilitates the identification of skill deficiencies in a design team given the design programme or project to be undertaken. Based on these deficiencies, considered improvements to the design team are proposed. The effects of these improvements are then assessed in terms of estimated time to complete the design programme or project, engineer utilisation cost, and the degree to which any imbalance in the design team has been redressed.

Engineering industry provided practical case studies in order to enable the methodology to be evaluated. Two case studies have been used since the design teams within each company are modelled differently. Armstrong Technology Associates were able to identify deficiencies and assess proposed improvements within their single-skilled, multi-disciplinary design team, i.e. the recruitment of two additional consultant electrical engineers. In addition, domnick hunter limited were able to determine the most appropriate modelling and development of their multi-skilled, multi-disciplinary design team. As such, the implementation of these changes to the design teams would lead to reductions being achieved in the time and cost of the design programme / design development phase.

Future work in the area of research covered in this paper will be directed toward developing formalised methods to enable the derivation of skill coefficients for engineers. A possible starting point in this area could be the consideration of engineer attributes such as experience, qualifications, personality and knowledge held.

Acknowledgements

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