Open Access
2021, 18(4) Supplement: 1423-1430

Baghdad Science Journal

P-ISSN: 2078-8665
E-ISSN: 2411-7986

DOI: https://dx.doi.org/10.21123/bsj.2021.18.4(Suppl.).1423

Unifying The Evaluation Criteria Of Many Objectives Optimization Using Fuzzy Delphi Method

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Received 15/10/2021, Accepted 14/11/2021, Published 20/12/2021

Abstract:

Many objective optimizations (MaOO) algorithms that intends to solve problems with many objectives (MaOP) (i.e., the problem with more than three objectives) are widely used in various areas such as industrial manufacturing, transportation, sustainability, and even in the medical sector. Various approaches of MaOO algorithms are available and employed to handle different MaOP cases. In contrast, the performance of the MaOO algorithms assesses based on the balance between the convergence and diversity of the non-dominated solutions measured using different evaluation criteria of the quality performance indicators. Although many evaluation criteria are available, yet most of the evaluation and benchmarking of the MaOO with state-of-art algorithms perform using one or two performance indicators without clear evidence or justification of the efficiency of these indicators over others. Thus, unify a set of most suitable evaluation criteria of the MaOO is needed. This study proposed a distinct unifying model for the MaOO evaluation criteria using the fuzzy Delphi method. The study followed a systematic procedure to analyze 49 evaluation criteria, sub-criteria, and its performance indicators, a penal of 23 domain experts, participated in this study. Lastly, the most suitable criteria outcomes are formulated in the unifying model and evaluate by experts to verify the appropriateness and suitability of the model in assessing the MaOO algorithms fairly and effectively.

Keywords: Evaluation Criteria, Fuzzy Delphi, Many Objectives Optimization, Unifying Model.

Introduction:

In many-objective optimization algorithms (MaOO), the performance evaluation considers a critical matter in determining the accuracy of the results [1, 2]. Many evaluation criteria were proposed in the context of MaOO to evaluate the MaOO algorithms. However, MaOO evaluation performance considers a primary challenge in the optimization process due to the complexity of MaOPs and the ambiguity of criteria selection that depend mainly on one or two of the evaluation criteria metrics[3,4]. Despite the fact that some of these criteria have been criticised in the literature, they are still chosen at random and used to evaluate the performance of MaOO algorithms. In addition, the process of selecting any of these criteria and its metrics for evaluation remains an open question[5,6]. This study aims to unify the most suitable evaluation criteria for evaluating the MaOO performance using the fuzzy Delphi method.

Fuzzy Delphi Method (FDM), proposed based on integrating the Delphi method into fuzzy theory[7] to overcome the Delphi method drawbacks. FDM has proven effectiveness in widely employed for unifying, screening and forecasting, assessment, standardization, and criteria identification in various domains[7-13]. Mainly, FDM provides appropriate results when making decisions regarding objective issues needed, while the involving criteria are not unified[13,14]. The FDM provides a resilient framework that can handle the lack of precision and clarity. The incomplete or inaccurate information is considered an issue in decision making.

Furthermore, subjectivity in the decisions made by the decision-makers caused uncertain results. FDM is tailored to the fuzzy environment to handle imprecise descriptions and human subjectivity[12]. Employing fuzzy numbers can leave the impression of using an appropriate method for decision-making[8]. Therefore, FDM is the best method for assessing and unifying the most effective criteria with high flexibility scale[8,9,13]. Moreover, all vital information will be considered without any missing because the membership degree effectively considers all experts' preferences[9,14,15].

Methodology:

The process for unifying the evaluation criteria model in the context of MaOO is introduced in this section. The process comprises three steps, as shown in Figure 1, which are: (1) MaOO criteria identification and analysis, (2) fuzzy Delphi analysis, (3) development and validation of the proposed MaOO criteria evaluation model.

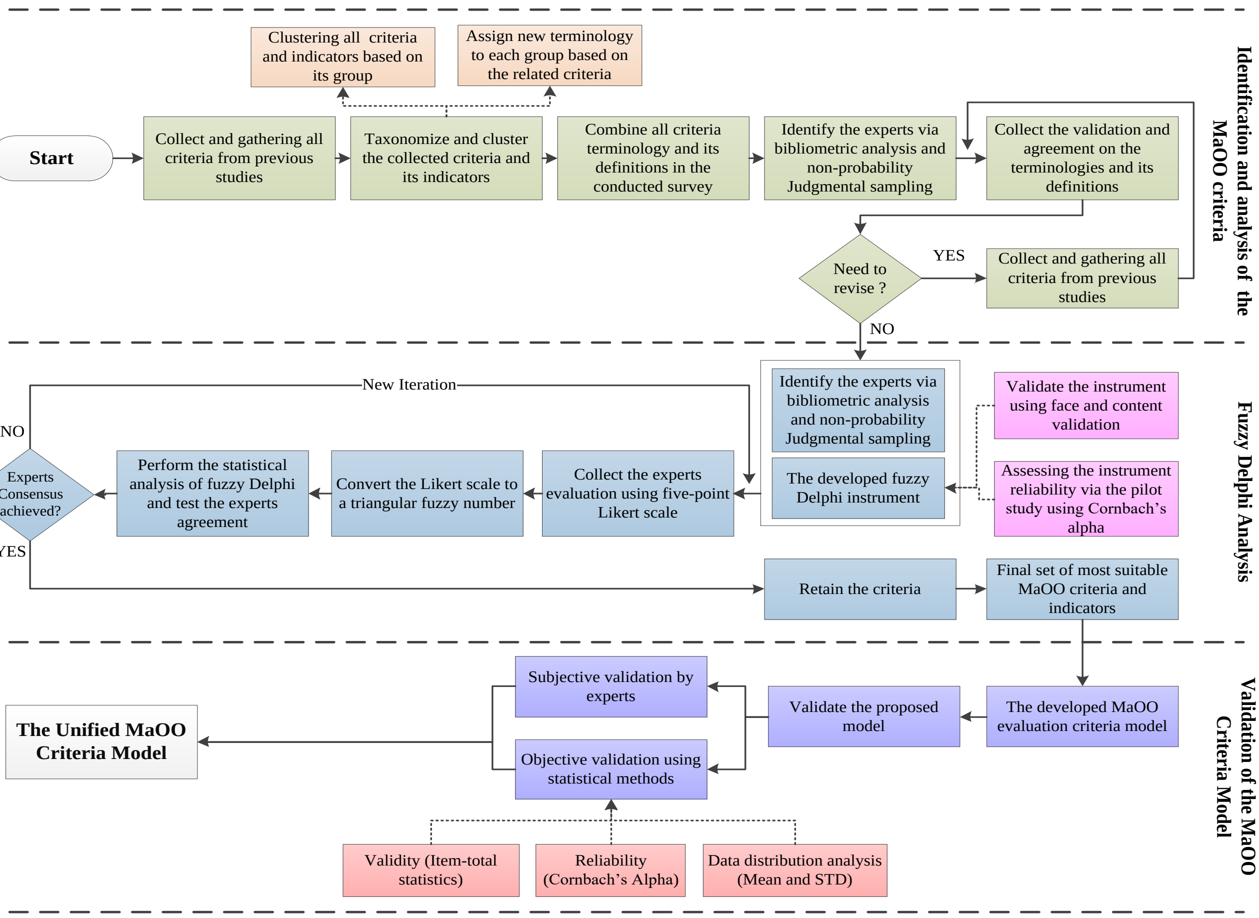

Figure 1. The processing steps for unifying the evaluation criteria of the MaOO

Based on Figure 1, the first step for unifying the MaOO criteria is collecting, identifying, and analysing all MaOO evaluation criteria to criticize and categorize them based on their group. According to study[16] there are 49 criteria, sub-criteria, and indicators are used and developed to assess the performance of the MaOO algorithms, which are classified and presented as will present in the results section; Second step is Fuzzy Delphi Analysis (FDM) which consists of five stages. *Stage 1:* First, the panelist of experts from the domain are selected, while the recommended number of experts range is between (10-15)[17]; this range is sufficient when their backgrounds are the same, and uniformity is high. However, some studies included 50 specialists[18]. *Stage 2*: formulate the expert evaluation form (questionnaire) to collect the expert consensus over the studied criteria using the five Likert scale[19,20]. *Stage 3*: Data dissemination and data collection: the experts' feedback was collected through the developed questionnaire using an online survey[21]. *Stage 4:* the collected data of expert evaluation per criteria convert from linguistic scale to triangular fuzzy number using table 1. Lastly, *stage 5:* in this step, the degree of agreement for each criterion based on expert consensus are computed. Three acceptance conditions are employed, which are, a) the results of applying vertex method to find d value for each criterion should be less or equal to 0.2[22]; b) the percentage consensus for each sub-criterion and overall should be greater than 75%[23]; and c) the average of the fuzzy number for each criterion should be greater than α-cut of 0.5 value. This value supports the sensible reasoning that only those elements from the fuzzy support set with 'sufficiently large' group grades are included[24]. Consequently, the results of the criterion must pass all three conditions[13,14], then this criterion gains the expert consensus and will be included in the unified model; otherwise, it will be omitted; Lastly, the validation step as demonstrated in Figure 1.

Results and Discussion:

Many performance indicators proposed to evaluate objective optimization algorithms. Some of them gradually decayed as it's inefficient to work with more than three objectives, while many others are developing to assess MaOO algorithms' performance. However, there is still an issue in evaluating the MaOO algorithms when it's come to select the evaluation criteria for benchmarking or assessing the MaOO algorithms, as there is no clear evidence of the reason behind using specific one or two indicators amongst others. Thus, proposing an evaluation criteria model is a necessity that aims to unify the most suitable criteria for MaOO. As present in the methodology section, the process of developing an evaluation criteria model comprises three steps:

(1) Identify the evaluation criteria for MaOO: In this section, all criteria, sub-criteria, and indicators are collected, combined, and categorized from literature. A summary of them recalled and listed down here as shown in Table 1.

(2) fuzzy Delphi analysis: As mentioned in methodology section, the fuzzy Delphi method was employed to analyze the experts' consensus on "MaOO evaluation criteria" to identify the most suitable criteria. This step started by developing a questionnaire for fuzzy Delphi analysis as an instrument for collecting expert opinions over the 49 criteria, sub-criteria and its indicators identified, collected and analysed in the previous step and ending with testing the acceptance conditions on the output criteria set. The processing results of these steps are presented in detail as following: *Step 1:* Expert selection is a critical task: For expert selection, the non-probability purposive sampling was used based on the following inclusion criteria: (a) MaOO developer specialist either industrial or academician (b) Those who have possessed a remarkable research work in the field of MaOO. (c) Minimum 5 years of experience in the study field. About 250 experts from around the world contacted and invited to participate through LinkedIn or their official email address; 50 of them expressed their readiness for participating in this research study. *Step 2:* Developing the expert questionnaire; Parallelly, the fuzzy Delphi analysis questionnaire formulated for the 49 criteria, sub-criteria, and indicators items. The face and content validity were utilized to check the validity and reliability level of the expert questionnaire before conducting the actual study. The content validity index (CVI) results were between 0.857 (6/7) to 1 (7/7), shows that all questionnaire items are relevant and valid. While the average item level (S-CVI/Ave) and Universal Agreement (UA) among experts (S-CVI/UA) were 0.994 and 0.960, respectively. Thus, the developed instrument of this study is valid[25,26]. The first version of the fuzzy Delphi analysis questionnaire was sent for a pilot study to test its reliability. Twenty participants from University Putra Malaysia (UPM) and the University of Baghdad were invited to answer the survey. The collected responses were analyzed using SPSS to compute the reliability level. The accepted Cronbach's alpha is 0.75, the Cronbach's alpha for the fuzzy Delphi instrument was 0.944.

Baghdad Science Journal
P-ISSN: 2078-8665
E-ISSN: 2411-7986

Table 1. The summary of the criteria list of MaOO and its indicators

Main Criteria	Sub-criteria		Indicator	Citation
Pareto	Single Direction	Convergence	Generation_Distance	[8]
			Norm	[9]
			Local_Generation_Distance (LGD)	[10]
			The_additive_epsilon	[11]
			The_Power_Mean_of_Generational_Distance	[12]
			Pertinence_Metric	[13]
			Convergence_Metric	[14]
			MinSum_SumMin	[15]
		Uniformity Diversity	Spacing_metric	[16]
			The_Pure_Diversity	[17]
			Maximum_Spread	[9]
			The_Diversity_Measure	[18]
			The_Sigma_Diversity_metric	[19]
	Multi Directions	Uncertainty Distribution	Imprecision	[20]
			Spread_Metric (S or Δ metric)	[20]
			Diversity_Comparision_Indicatior	[18]
		Comprehensive	R2_Indicator	[19]
			The_Generalized_Spread	[21]
			The_Hierarchical_Cluster_Counting	[13]
			Hypervolume_metric	[22]
			Inverted_Generation_Distance	[23]
			Inverted_Generation_Distance_Plus	[24]
			Local_Inverted_Generation_Distance	[10]
			Polar_Metric	[25]
			Power_mean_Inverted_Generation_Distance	[26]
			Two_Set_Converage	[8]
			Hyperarea_Ratio	[19]
			Averaged_Hausdorff_Distance	[27]
			G_Indicator	[19]
	Cardinality		Changed_Pareto_Domination_Ratio	[28]
			Success_Rate	[29]
			Sigma_metric	[30]
			Final Nondominated Population Size in the Target Region (PS-T)	[5]
			Pareto Subset (PS)	[12]
	Time		Error_ratio	[5]
			No._of_Comparision	[31]
			Total_run_time	[32]
			T_Metric	[20]
			Algorithm Running Efficiency (ARE)	[33]
			Performance_Score	[34]

Step 3: Survey dissemination and data collection; The online survey was distributed using email tool and weblink on Smartsurvey.com and shared with the experts from around the world, who were instructed to use a five Likert scale to express their agreement level for each criterion, sub-criterion, and indicator. Twenty-three experts submitted a completed response, the response data exported from the questionnaire as an input to analyse in fuzzy Delphi method. *Step 4:* In this step, all experts' collected results are converted into fuzzy triangular numbering from the linguistic variables as shown in Table 2, the process of converting the main criteria data to fuzzy numbers. The exact process applied to the rest of the subcriteria and indicators.

Table 2. Linguistic variables for five scales

Likert Scale	Linguistic term	Fuzzy Scale
1	Strongly Disagree	(0.0,0.0,0.2)
2	Disagree	(0.0,0.2,0.4)
3	Moderate	(0.2,0.4,0.6)
4	Agree	(0.4,0.6,0.8)
5	Strongly Agree	(0.6,0.8,1.0)

Step 5: The last step is testing the acceptance conditions for each item (i.e., criteria, subcriteria, and indicators). Table 3 shows the results of the three conditions representing the experts’ consensus on the main criteria, the same process applied to the rest of the subcriteria and indicators.

Table 3. The conditions result of the main criteria of the fuzzy Delphi method

	Expert Number	Pareto Criterion	Cardinality Criterion	Time Criterion
	1	0.04	0.07	0.1
	2	0.04	0.07	0.1
	3	0.04	0.42	0.1
	⋮	⋮	⋮	⋮
	23	0.16	0.42	0.1
1st Condition	The value d of each item	**0.108**	**0.153**	**0.113**
	The value of d for all		**0.124**	
	Accept each item has d <=0.2	**Accepted**	**Accepted**	**Accepted**
2nd Condition	Percentage of Each Item (d ≤ 0.2)	**87%**	**78%**	**91%**
	The overall percentage >=75%		**86%**	
	Accept each item has >=75%	**Accepted**	**Accepted**	**Accepted**
3rd Condition	Average of fuzzy numbers (expert response)	0.443 0.643 0.843	0.261 0.443 0.643	0.322 0.522 0.722
	Average of fuzzy numbers	**0.64**	**0.45**	**0.52**
	Rank	**1**	**3**	**2**
	Accept each item has >=0.5	**Accepted**	**Rejected**	**Accepted**

As shown in Table 3, the cardinality criterion passed the first two conditions, but the third condition didn't pass, in conclude, this criterion is rejected, and consequently, the indicators of this criterion will be rejected, as well. The unified model of MaOO evaluation criteria, subcriteria, and indicators analysis results based on fuzzy Delphi analysis is demonstrated in Table 4.

Table 4 demonstrates the unified model result based on the fuzzy Delphi process of the acceptance conditions for all tested criteria, subcriteria, and indicators. Out of three main criteria, two criteria passed all three conditions namely the Pareto and Time, while the cardinality criterion rejected. For time criterion's indicators, two indicators are accepted, which are ARE and Performance score. For Pareto criterion, all other subcriteria with single and multi-directions got the experts' consensus on its suitability for evaluating the MaOO algorithms. However, the accepted indicators per each subcriterion were as following; For convergence criterion out of eight indicators, six indicators were accepted: generation distance, LGD, the additive epsilon, the power mean of generational distance, pertinence metric, and convergence metric. For the uniformity criterion, spacing metric accepted. For Diversity criterion, out of four indicators, three accepted the pure diversity, maximum spread and the diversity measure; under uncertainty criterion, the imprecision indicator was accepted. While four indicators of distribution criterion accepted, which are Spread_Metric (S or Δ metric), Diversity Comparison indicator, R2 Indicator, The Generalized Spread. Lastly, six indicators of comprehensive criterion accepted Hypervolume metric, Inverted Generation Distance, Inverted Generation Distance Plus, Local Inverted Generation Distance, Hyperarea Ratio and Averaged Hausdorff Distance.

(3) The Validation of the Proposed Most Suitable Criteria Model: The absent of unified set (set of the most suitable criteria) considered one of the main issues in evaluating and comparing the competitive MaOO algorithms, while no evidence on the propriety of the selected criteria for assessing the performance of MaOO algorithms [27]. Thus, unifying a model for the set of most suitable evaluation criteria is a necessity. It's worth mentioning here that the development of new indicators is continuing task. The researchers might continue developing new indicators as natural progress to fulfil the needs and align with the MaOO sector's improvement. The unifying MaOO criteria model is designed to be a reference for evaluating MaOO competitive algorithms' performance. In addition, it is flexible enough to provide a systematic work shed for any new related indicator of MaOO to be added. For validation, a survey was sent with the results of most suitable criteria set (the proposed model) to the MaOO experts to validate the unified criteria set. For model validity and suitability in the context of MaOO the proposed model has been sent to the experts for validation. To avoid any bias or influence, the consulting expert kept anonymous for the truth and fairness evaluation.

Table 4. The Unified model of evalution criteria of MaOO

Pareto	Single Direction	Convergence	Generation_Distance
			Local_Generation_Distance (LGD)
			The_additive_epsilon
			The_Power_Mean_of_Generational_Distance
			Pertinence_Metric
			Convergence_Metric
		Uniformity	Spacing_metric
		Diversity	The_Pure_Diversity
			Maximum_Spread
			The_Diversity_Measure
		Distribution	Diversity_Comparision_Indicatior
			R2_Indicator
			The_Generalized_Spread
	Multi Directions	Comprehensive	Hypervolume_metric
			Inverted_Generation_Distance
			Inverted_Generation_Distance_Plus
			Local_Inverted_Generation_Distance
			Hyperarea_Ratio
			Averaged_Hausdorff_Distance
Time			Algorithm Running Efficiency (ARE)
			Performance_Score

As shown in Figure 2, the experts have been asked to validate the proposed model and show their level of acceptance, and the results of their responses support for the proposed model and its validity, out of 21 experts who participated in the validation process (14; 66.67%) show their acceptance and (6; 28.57%) was strongly accepted, while 4.76% (1 expert) request to revise the model and replace the abbreviation or acronym name with the full name and the researcher already applied that, and the final approved model presented in Table 4.

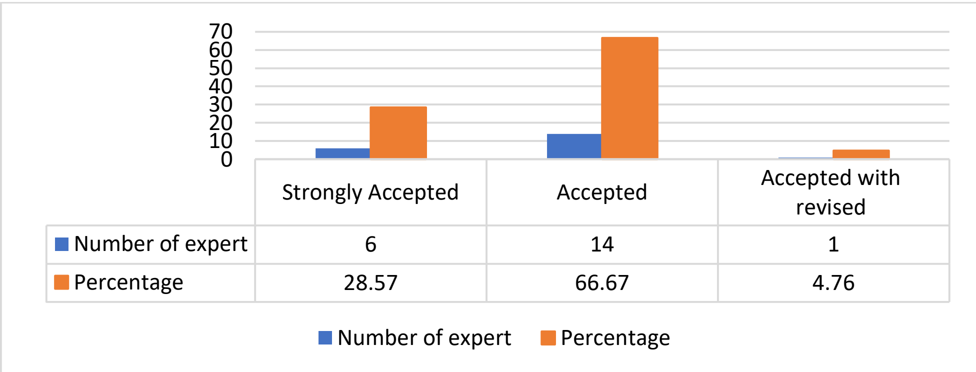

Figure 2. The acceptance of the validity of the proposed model

Conclusion:

The Many Objective Optimization algorithms (MaOO) evaluation criteria play a critical role in evaluating the competition MaOO algorithms. Although these criteria have been criticized in literature, they are employed in the evaluation randomly, and the process of selecting them remains unclear. Thus, the need for unifying the criteria set became inevitable. This study presents the processing results of developing criteria model for many objectives optimization algorithms. The fuzzy Delphi analysis test and refine the 49 criteria, subcriteria, and its indicators. The fuzzy Delphi method's final results narrowed the criteria set down to 31 of the most suitable criteria set. The statistical analysis of the experts' evaluation proved the validity of the proposed criteria model and its suitability for evaluating the MaOO algorithms. These results contribute to the body of knowledge and provide a flexible unified model of evaluation criteria for MaOO algorithms. In future work and to provide an exhaustive evaluation methodology, the importance level of each of these suitable criteria set needs to study and determine accordingly.

Authors' declaration:

- Conflicts of Interest: None.

- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.
- The author has signed an animal welfare statement.
- Ethical Clearance: The project was approved by the local ethical committee in University of Putra Malaysia.

Authors' contributions:

Rawia Tahrir Mohammed conceived of the presented idea in addition and performed the computations.
Razali Yaakob, Nurfadhlina Mohd Sharef, and Rusli Abdullah verified the analytical methods.
Rawia Tahrir Mohammed, Razali Yaakob, Nurfadhlina Mohd Sharef, and Rusli Abdullah contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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توحيد معايير التقييم للعديد من الأهداف التحسين باستخدام طريقة FUZZY DELPHI

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الخلاصة:
يتم استخدام العديد من خوارزميات التحسينات الموضوعية (MaOO) التي تهدف إلى حل المشكلات ذات الأهداف المتعددة (MaOP) (أي المشكلة ذات أكثر من ثلاثة أهداف) على نطاق واسع في مجالات مختلفة مثل التصنيع الصناعي والنقل والاستدامة وحتى في القطاع الطبي . تتوفر طرق مختلفة لخوارزميات MaOO ويتم استخدامها للتعامل مع حالات MaOP المختلفة. في المقابل ، يتم تقييم أداء خوارزميات MaOO بناءً على التوازن بين تقارب وتنوع الحلول غير المسيطرة المقاسة باستخدام معايير تقييم مختلفة لمؤشرات أداء الجودة. على الرغم من توفر العديد من معايير التقييم ، إلا أن معظم عمليات التقييم والقياس المعياري لـ MaOO باستخدام خوارزميات حديثة تعمل باستخدام واحد أو اثنين من مؤشرات الأداء دون دليل واضح أو تبرير لكفاءة هذه المؤشرات على غيرها. وبالتالي ، هناك حاجة إلى توحيد مجموعة من أنسب معايير التقييم الخاصة بـ MaOO. اقترحت هذه الدراسة نموذجًا موحدًا متميزًا لمعايير تقييم MaOO باستخدام طريقة دلفي الضبابية. اتبعت الدراسة إجراء منهجيًا لتحليل 49 معيارًا للتقييم ، ومعيارًا فرعيًا ، ومؤشرات الأداء الخاصة بها ، وشارك في هذه الدراسة 23 خبيرًا في المجال. أخيرًا ، يتم صياغة نتائج المعايير الأكثر ملاءمة في النموذج الموحد وتقييمها من قبل الخبراء للتحقق من ملاءمة النموذج وملاءمته في تقييم خوارزميات MaOO بشكل عادل وفعال.

الكلمات المفتاحية: معايير التقييم ، نموذج دلفي الضبابي ، تحسين العديد من الأهداف ، النموذج الموحد.