Közgazdász Fórum
Forum on Economics and Business
22(139), 62–76.
2019/2

Simplification of sustainable development indicator systems through Principal Component Analysis

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The main aim of this paper is to reduce the indicators of the European Union's Sustainable Development Strategy and the United Nation's 2030 Agenda indicators through Principal Component Analysis, with minimal information loss. The European Union's Sustainable Development Indicator System (EU SDIs) was grouped around 130 indicators based on 10 topics. Over time, this indicator system has been reworked due to the overriding goals, objectives and the progress made. In 2015, in Paris, 193 UN member states signed the next global sustainability programme. The 2030 Agenda framework strategy uses indicators that are difficult to interpret because of their size and their progress. Within the strategy, 244 indicators have been created, covering the three aspects of sustainable development. The current study describes a method to reduce the sustainable development indicators that are part of the strategy. With this reduction, progress on sustainable development goals can be more easily understood at the European Union level. The principal component determines the properties, characteristics and indicators that have the greatest impact on sustainability. With this method, I can reduce the size of the database and, at the same time, drawing conclusions becomes easier and faster.

Keywords: sustainable development indicator system, EU Sustainable Development Strategy, UN 2030 Agenda, Principal Component Analysis.

JEL codes: O52, Q01, Q56.

Introduction

The Club of Rome made the first steps in the direction of sustainable development (Rosta 2008). Essentially, steps have been taken towards sustainable development since 1968. Many international conventions (Stockholm – 1972, WCED – 1987, Rio de Janeiro – 1992, Johannesburg – 2002) emerged, trying to find the answer to economic, social and environmental challenges (Láng 2001). The real breakthrough came from the Brundtland Commission, which developed the three pillars (economic, environmental, social) and the concept of sustainable development (WCED 1987).

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Publishers: Hungarian Economists' Society from Romania, Department of Economics and Business Administration in Hungarian Language at Babeș–Bolyai University, and the Partium Christian University
ISSN: 1582-1986 www.econ.ubbcluj.ro/kozgazdaszforum

In Paris, 193 members of the United Nations (UN) gathered to discuss the new sustainability programme, resulting in *Transforming Our World: the 2030 Agenda for Sustainable Development*. This 2030 Agenda is valid for all the nations without exception. They formulated 17 goals (SDGs) on the basis of which the European Union developed its new sustainable development indicators (UN 2015).

My research is based on two sustainability strategies, on the European Union's *Sustainable Development Strategy* (referred to as EU SDS, COM 2001) and on the UN strategy entitled *Transforming Our World: the 2030 Agenda for Sustainable Development* (UN 2015), which provides its conceptual framework and indicator system. The period examined in the study is 2015, the year of EU SDS completion and adoption of the 2030 Agenda strategy, which is essentially the only year for comparison.

In terms of Principal Component Analysis, we speak of a statistical procedure that transforms a set of variables using a linear transformation. It ensures maximum information retention; consequently, the lowest amount of information is lost. Why is it essential to keep information at a high level? Because, in general, it is difficult to create a system for sustainable development and sustainability, even more complicated with so many indicators.

My goal was defined to provide a reduction with the help of Principal Component Analysis. The main objective of the study is to reduce the high number of indicators in order to make the goals of strategies and systems more transparent.

To demonstrate my goal, I will first introduce the two most important theoretical strategies that seek to address the issue and objectives of sustainable development worldwide. The results of the research will be presented below. The complexity of the two indicator systems comes to the fore when we want to analyse a particular region, a country in the European Union or simply the European Union itself. Fewer indicators make it easier to analyse and draw conclusions.

Conceptualisation and methodology

Sustainable Development Strategy of the European Union

In preparing the integration of sustainable development into different policies, social interest groups, previous treaties and the Cardiff Summit played a decisive role (Lyytimäki et al. 2011). In 2001, the Council of the European Union approved the Sustainable Development Strategy at the Gothenburg Summit (EC 2001), which complements the Lisbon Treaty (EU 2007) with the environmental dimension (COM 2001). In Gothenburg, objectives were identified that needed to be integrated into economic, social and environmental policies to create the conditions for sustainable development in the European Union (Schmuck 2002). It is a long-term strategy, which is based on the three dimensions (economy, society, environment) of the Brundtland Commission. It coordinates the policies in order to meet present and future generations' needs as well as to offer them better living conditions and welfare.

The EU SDS set the following goals (EC 2001):

- Fight against climate change;
- Sustainable production, consumption and transport;
- Public health, global poverty;
- Preserving production resources;
- Addressing the issues of ageing population and social exclusion; poverty reduction, immigration management.

We may view the EU SDS goals as supplementing the Lisbon Treaty because they define threats which must be fought. The set of objectives was designed with catalyst and bridging roles in mind. The bridging role means that they need to develop a strategy which concentrates on the emerging threats: climate change, public health, poverty, the mix of high life expectancy with low birth rate, biological diversity under threat, traffic failure (COM 2001).

The EU SDS was modified in 2006 and suspended in 2015 after the release of the UN's 2030 Agenda (UN 2015). The modification meant that the renewed EU SDS set out an integrated and coherent strategy on how the EU could more effectively live up to its long-term commitment to the challenges of sustainable development (EC 2006). In the interpretation of Sabel and Zeitlin (2010), the renewed strategy distinguished between "general objectives" and more specific "operational objectives and targets". For example, the overarching goal of "Climate change and clean energy" was to limit climate change and its costs and negative impacts on society and the environment. In terms of duration, it was in force for 14 years.

Sustainable development indicators of the EU

The European Union's sustainable development indicator system (EU SDIs) is grouped around 130 indicators based on 10 topics. However, not all of the indicators can be measured (numerically five) (Kis-Orloczki 2013). The themes can also be grouped according to the Brundtland Commission's three-dimensional sustainability system.

The SDI system is also designed to show how the EU has made progress towards its goals which are described by the EU SDS, the Sustainable Development Strategy (Eurostat 2015). In fact, the strategy also has a controlling role in achieving the goals. In order to fully understand the path to sustainable development, it is advisable to look at all the indicators. Eurostat published biennial indicators of sustainable development which gave the Member States a summary of their own and other Member States' performance. The collection of indicators for this strategy ceased in 2016.

Transforming Our World: the 2030 Agenda for Sustainable Development

After completion of the United Nations' framework strategy on Millennium Development Goals (MDGs) (UN 2000), it was necessary to develop a new, long-term programme package that would continue and renew millennium development ambitions and goals.

The strategy entitled *Transforming Our World: the 2030 Agenda for Sustainable Development* was adopted in September 2015 by 193 UN member states (UN 2015). Compared to the MDGs, the similarity is that both strategies include goals, objectives and indicators and the SDGs were typically 'built' for purposes that could not be or could be only minimally achieved or that had been expanded during MDG implementation (Walsh et al. 2020). The 2030 Agenda includes appropriate ways to distribute aid to poor countries, the role developed countries have and how much responsibility they have to take in the period from 2015 to 2030 (Jancsovszka 2016; Bebbington–Unerman 2018).

The 2030 Agenda focuses on goals that seek to develop a more comprehensive approach to sustainable development. In terms of the number of goals, 12 were initially set, later supplemented by 7 other goals. The 2030 Agenda had set a total of 17 targets before the adoption of the framework that best reflected the aspiration for sustainable development (Griggs et al. 2014). The creators of the strategy complemented the 17 sustainable development goals (SDGs) with 169 objectives that are even more capable of expressing what they want to achieve by 2030 (de Vries 2015). They demonstrate ambitious plans and levels of new universal programmes. They take the bold and transformative steps that make sustainability and the world flexible. The framework can also be described as the 5Ps (Planet, People, Peace, Prosperity, Partnership), as it focuses on these five areas (Chakrabarti et al. 2018).

In March 2016, the UN Statistical Commission adopted an indicator system that can best measure the sustainability goals formulated in the 2030 Agenda. Globally, 244 indicators have been developed, with 154 being currently relevant at the European Union level. These sustainability indicators are collected by Eurostat with the help of the Member States in order to monitor the progress of the countries and the European Union towards the various, specific objectives. The indicators can be further broken down, although not all indicators contain aggregated data, so there are 223 indicators in total after division at EU level. The breakdown of indicators means that, in some cases, such as the 'employment rate', an indicator can be broken down into the ratio of males to females and also include aggregated data (total). When aggregate data were available, I used it in the analysis. In other cases (e.g. energy dependence), I was able to distinguish two versions of the indicator, gaseous and solid fuels, so both were included in the database.

In order to achieve the best and most efficient implementation, the goals should not be reached individually but combined and they should be managed as far as possible. By implementing the framework, they are confident that the lives of the citizens will change significantly and the Earth will become a much more liveable place.

Research question

The main objective of the study is to reduce the high number of indicators in order to make the goals of strategies and systems more transparent.

My main research question is *whether PCA is a suitable method for reducing the number of EU SDS and 2030 Agenda indicators with minimal loss of information.*

Data and method

Data related to the indicators of the EU SDS and the 2030 Agenda are available for all 28 EU Member States in the Eurostat database. For the purpose of my study, I use data from 2015, which is the year of EU SDS completion and adoption of the 2030 Agenda strategy and therefore the only year when indicators from the two sets are comparable. The two strategies contain a total of 10,836 data points for year 2015. In order to make the overview and interpretation easier, the enormous number of indicators need to be reduced, but without loosing relevant information.

The high number of indicators was reduced using Principal Component Analysis (PCA), a statistical method that, with linear transformation, converts a large variable set into a new, reduced set of uncorrelated variables (Székelyi–Barna 2002). The method is designed to minimise the loss of information (preserve most of the content) and thereby select those principal components whose information content (variance) is the highest. More simply put, those with the greatest weight are selected. We can draw almost the same conclusions from the principal components that have been created as from the original variables (Ketskeméty et al. 2011). In the original model, the statistical population characterised by the variable p is characterised by the variable k << p from which the principal components are derived. The conclusions of our k-dimensional analysis for this p-dimensional population will also be correct (Ketskeméty 2012). The method can only be performed if the following steps are maintained:

- Involving variables into the model;
- Assessing data suitability on the basis of the KMO criterion;
- Suitability of variables – adequately characterise the principal component;
- Rotation of factors.

Without following these steps, the method cannot be performed. This statistical method uses the full variance and the resulting factors can include both the individual and error variance (Sajtos–Mitev 2007). The analysis was performed using the IBM SPSS software.

Results of the Principal Component Analysis

I have carried out PCA for each of the 10 EU SDS themes and the 17 SDGs. Indicators on the four levels (main, operative, explanatory, contextual) can break down into further sub-indicators. The EU SDS has a numerical index of 126, with a total of 200 sub-areas and with some of them also differentiated according to gender, thus the final number of indicators reaches 162. The SDGs have 223 associated indicators.

Due to space limitation in this article, I will present the detailed analysis only for one EU SDS theme and one SDG and I will give an overview of the results for all EU SDS and 2030 Agenda goals.

Results of the PCA for EU SDS Theme 2 – Sustainable consumption and production

Theme 2 of the EU SDS has 22 associated indicators. The first PCA step is to include in the analysis the variables (indicators) that are relevant to the given goal. There are a number of methods to assess the values of the KMO (Kaiser–Meyer–Olkin) criterion. The values are interpreted according to Molnár (2015). The KMO value is the average of the MSA (sample suitability measure) values. The KMO value applies to all variables, while the MSA is used only for some variables. We accept it if the value is above 0.5, but lower values cannot be accepted (Sajtos–Mitev 2007). A KMO $\geq$ 0.5 is weak, a KMO $\geq$ 0.6 is medium, a KMO $\geq$ 0.7 is appropriate, a KMO $\geq$ 0.8 is good and a KMO $\geq$ 0.9 is very good (Molnár 2015).

Table 1 shows the results of the KMO and Bartlett's test. The KMO value is 0.761, thus factor analysis can be performed.

Table 1. KMO and Bartlett's test result (theme 2)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.761
Bartlett's Test of Sphericity	Approx. Chi-Square	1197.642
	df	91
	Sig.	.000

Source: own research

In the next PCA step, the question arises as to whether the variables really characterise the properly formed principal component. The Total Variance Explained table shows the information content presented by the variables. The PCA makes sure that at least 50% of the information content is retained (cumulative column). If the value falls below the desired limit, it does not make sense of the principal components. It could happen that we may not be able to deduce the conclusions from the principal components that have been created as compared to the pre-transformation data set. In this case, the solution would be to create the next principal component. Table 2 shows the values of the information obtained.

Table 2 shows how much of total information is covered by the four principal components. In case of 13 principal components, it would reach 99.987% and with 14, 100%. The total explanatory force of the four principal components is nearly 86% and only 14% of all information is lost. Principal components are aligned according to the size of the variance. The first factor has the highest eigenvalue/explained variance (7.415/52.966), the second stands at 2.001/14.293 and so on.

Table 2. Information content of principal components belonging to theme 2

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	7.415	52.966	52.966	7.415	52.966	52.966	7.227
2	2.001	14.293	67.259	2.001	14.293	67.259	3.027
3	1.362	9.728	76.987	1.362	9.728	76.987	1.594
4	1.205	8.610	85.597	1.205	8.610	85.597	1.225
5	.770	5.499	91.096				
6	.463	3.307	94.403				
7	.335	2.396	96.798				
8	.212	1.518	98.316				
9	.132	.942	99.259				
10	.042	.297	99.556				
11	.034	.239	99.795				
12	.019	.137	99.933				
13	.008	.054	99.987				
14	.002	.013	100.000				

Extraction Method: Principal Component Analysis.
a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Source: own research

For a better understanding of principal components, the rotation of the factors must be performed. During the rotation, neither communality nor all the variations explained will change, only the eigenvalue/explained variance. I used the so-called non-orthogonal rotation method (the *Promax* method), which performs better when the primary purpose of the research is to interpret the factors and when a large database is available, like in the present case. Table 3 shows the rotated factor weight matrix for theme 2.

When we interpret the factors, it is advisable to examine the factor weights and their explanation more thoroughly. Based on Sajtos–Mitev (2007), the factor weight is the correlation between the variable and the factor, and its square gives the degree of variation explained by the factor in the variable. The greater the weight of the factor is, the more the factor will explain the variance of the variable. As a general rule, the factor weight must reach at least 0.3 in absolute value.

Table 3. Rotated factor weight matrix for theme 2

Indicators	Component			
	1	2	3	4
SDI_2_1_7_emiss_of_non_methane_volatile_org_compounds_tonnes	.960	.379	-.084	-.072
SDI_2_1_2_res_prod_and_dom_mat_consump_thousand_tonnes	.954	.195	-.066	-.007
SDI_2_1_8_emiss_of_ammonia_tonnes	.953	.383	-.108	-.128
SDI_2_2_1_final_energy_consumption_by_sector	.951	.483	-.247	-.078
SDI_2_1_3_municip_waste_by_waste_man_oper_waste_tret_thou_tonnes	.943	.484	-.257	-.103
SDI_2_2_suppl_trans_and_consump_of_electricity_TOE	.940	.502	-.285	-.096
SDI_2_1_6_emiss_of_nitrogen_oxides_tonnes	.830	-.058	.369	.213
SDI_2_1_5_emiss_of_sulphur_oxides_tonnes	.770	-.219	.419	.334
SDI_2_resource_productivity_PPS_per_kilogram	.380	.858	-.160	-.068
SDI_2_1_1_2_final_consump_exp_of_househ_by_consump_purpose	-.174	-.768	.245	-.320
SDI_2_3_1_ecolabel_licenses	-.561	-.596	-.278	-.396
SDI_2_1_1_1_number_of_persons_in_households	-.120	-.232	.833	.022
SDI_2_1_4_gen_of_hazard_waste_by_economic_activity_kg_per_capita	-.139	-.417	-.424	.220
SDI_2_2_2_motorisation_rate	-.070	.142	-.121	.841

Extraction Method: Principal Component Analysis.
Rotation Method: Promax with Kaiser Normalization.

Source: own research

The larger the sample (df) is, the smaller the factor weight matrix is. The item number for theme 2 is 91, so the factor weight must be at least 0.580. Indicators with this value or higher belong to principal components.

For the EU SDS theme *Sustainable consumption and production*, we can conclude that, in addition to complying with Principal Component Analysis rules, 13 indicators (variables) were left out of the four principal components of the original 22 variables, thus the number of indicators was reduced by 41%. Indicator 2.1.4 – generation of hazardous waste by economic activity – was left out. The other indicators were dropped during the examination of communalities. This means that resource productivity (Euro/kg); generation of waste excluding major mineral wastes; resource productivity and DMC; municipal waste by waste management operations; area under agri-environmental commitment; area under organic farming and livestock density index were left out. The first principal component contains resource use in the EU, waste generation and energy consumption, household electricity. The second principal component includes indicators that imply the main indicator (resource productivity) of the theme and one contextual indicator, expenditure of households on final consumption. Both indicators are significantly related to Gross Domestic Product (GDP) because this variable is the basis for their calculation. The third and fourth principal components include just one variable each (the number of persons living in a household and the motorisation rate).

Results of the PCA for SDG 8 – Decent work and economic growth

SDG 8 – *Decent work and economic growth* – consists of nine indicators. Two of them (resource productivity and domestic material consumption) can be split into two sub-indicators, bringing a total of 10 variables to the analysis. The KMO and Bartlett's test is 0.748, which can be classified as adequate-good (Table 4).

Table 4. Proportion of variance for SDG 8 (KMO and Bartlett's test)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.748
Bartlett's Test of Sphericity	Approx. Chi-Square	212.520
	df	21
	Sig.	.000

Source: own research

The characteristics of variables and indicators are in the forefront of analysing each goal. Table 5 shows how much of the information they can keep in the process.

Table 5. Information content of the goal related to the economic dimension

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	3.262	46.604	46.604	3.262	46.604	46.604	3.234
2	1.578	22.550	69.154	1.578	22.550	69.154	1.622
3	1.004	14.346	83.500	1.004	14.346	83.500	1.060
4	.463	6.617	90.117				
5	.435	6.219	96.336				
6	.152	2.168	98.504				
7	.105	1.496	100.000				

Extraction Method: Principal Component Analysis.
a. When components are correlated, the sums of squared loadings cannot be added to obtain a total variance.

Source: own research

Three principal components have been created, retaining 83.5% of all information, so only 16.5% is lost. The first factor has the highest eigenvalue/explained variance (3.262/46.604), the second reaches 1.578/22.550 and the third, 1.004/14.346.

Table 6. Rotated factor weight matrix for SDG 8

Indicators	Component		
	1	2	3
sdg_08_30_employment_rate_20_to_64_years_total	.932	-.141	.142
sdg_08_40_long_term_unemployment_rate_total	-.926	-.085	-.141
sdg_08_20_young_peop_neither_in_empl_nor_in_educ_and_traning	-.913	.301	.016
sdg_08_11_investment_share_of_GDP_by_institut_sectors	.604	.551	.198
sdg_08_60_people_killed_in_accidents_at_work	-.047	.853	-.150
sdg_08_10_real_GDP_per_capita	.535	-.683	-.132
sdg_12_21_resource_product_and_domestic_material_consump_1000_t	.140	-.090	.970

Extraction Method: Principal Component Analysis.
Rotation Method: Promax with Kaiser Normalization.

Source: own research

For better interpretability, I used the *Promax* rotation method for SDG 8 as well (Table 6). The item number of SDG 8 is 21, therefore only the indicators with a factor weight of at least 0.89 in absolute value are considered to be relevant. The first principal component includes three indicators related to employment (employment rate, long-term unemployment rate and young people neither in employment nor in education and training). The third principal component is related to a single indicator (resource productivity and domestic material consumption). Thus, using the PCA method, I grouped the indicators related to SDG 8 around three principal components and I reduced their number from ten to four.

Overview of the PCA for all EU SDS themes and 2030 Agenda goals

The method described in the sections above was run for all EU SDS themes and 2030 Agenda goals and, as it can be seen from Tables 7 and 8, all of them met the criteria for Principal Component Analysis (KMO > 0.5).

In terms of their information content, these themes and goals are excellent at preserving the properties of the original database, namely their value is well above 50%. The number of principal components ranges from 2 to 4. In each case, the PCA method reduces the number of indicators. Thus, the answer to the main research question – *Is PCA a suitable way to reduce the number of EU relevant indicators related to the EU SDS and the 2030 Agenda with minimal information loss?* – is affirmative.

Table 7. Reducing EU SDS indicators

Themes	Value of KMO	Information content	Principal components	Initial/final number of indicators
Socio-economic development	0.710	71.648%	3	23/14
Sustainable consumption and production	0.761	85.597%	4	22/13
Social inclusion	0.694	80.833%	4	30/14
Demographic change	0.655	81.564%	3	11/3
Public health	0.717	81.376%	4	19/13
Climate change	0.744	76.292%	2	15/4
Sustainable transport	0.722	84.517%	4	15/10
Natural resources	0.508	66.855%	3	9/1
Global partnership	0.711	72.176%	4	12/10
Good governance	0.534	61.050%	2	6/0
			Total	162/82

Source: own research

Table 8. PCA results for the 17 Sustainable Development Goals

	Goal 1	Goal 2	Goal 3	Goal 4	Goal 5	Goal 6	Goal 7	Goal 8	Goal 9
KMO	0.702	0.614	0.722	0.688	0.655	0.542	0.553	0.748	0.587
Information content (%)	76.978	76.413	77.052	87.178	72.515	68.898	73.128	83.500	74.972
Number of principal components	3	3	3	3	4	3	3	3	3
Initial/final number of indicators	13/9	12/6	21/6	9/6	16/11	12/2	15/6	10/4	7/2
	Goal 10	**Goal 11**	**Goal 12**	**Goal 13**	**Goal 14**	**Goal 15**	**Goal 16**	**Goal 17**	
KMO	0.743	0.700	0.638	0.635	0.542	0.608	0.743	0.756	
Information content (%)	82.631	76.043	88.533	81.192	74.937	73.843	87.059	85.211	
Number of principal components	2	4	4	4	2	3	3	2	
Initial/final number of indicators	15/9	19/8	14/9	13/8	6/3	12/3	20/9	11/5	
	Total			223 initial indicators/106 final indicators					

Source: own research

Tables 7 and 8 provide evidence that the Principal Component Analysis is an appropriate method to decrease the high number of indicators related to the EU SDS and to the SDGs. With the help of PCA, I managed to reduce the 162 indicators of the European Union's Sustainable Development Strategy to 82 and the 223 indicators of the 2030 Agenda framework to 106 variables. In terms of their information content, both the 10 themes and the 17 goals meet the 50% information retention criterion, thus, the initial set of data is appropriately characterised. As a result of the reduction, the interpretation of sustainable development indicators has become simpler and more transparent, and sustainable development goals can be characterised more easily. My initial assumption was therefore proved to be correct. Overall, for the EU SDS, the number of indicators could be reduced by 49%, while, for the 2030 Agenda, by approximately 53%. By carrying out the PCA, the ten themes and the 17 sustainable development goals can be characterised more easily. The indicators that are most prominent and important within the objectives have come to the fore as best describing the goals. In this case, it is not necessary to examine as many indicators in order to draw conclusions.

Conclusion

Indicator systems monitoring sustainable development are extremely diverse and the themes and goals are quantified by almost 385 indicators, which – due to quantification – implies complexity when we want to examine a particular region or a country or even the indicator system. In order to address this and to make indicator systems more transparent, I wanted to use PCA.

In this study, I examined whether Principal Component Analysis could reduce the EU SDS and the 2030 Agenda indicator sets. Using this method, it turned out that the EU SDS indicators could be reduced by 49%, while the 2030 Agenda's 223 indicators for sustainable development could be reduced by 53% if only indicators with the greatest explanatory power were included into principal components. Thus, sustainable development themes, goals and objectives can be characterised by far fewer indicators and subsequent research will become easier because it is no longer necessary to pay attention to inappropriate indicators, those that do not properly characterise the given topic or objective. The principal components identified by the PCA method determine the properties and characteristics of indicators that have the greatest impact on the goals and objectives of sustainability and thus become more measurable in the analysis. In the case of other EU SDS and 2030 Agenda analyses, we do not have to deal with the dropped indicators.

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