Evaluation indicators analysis

Step 1:

We further adopt the weight calculation method and compute the composite index of the sustainability *F* based on [53]. The original data is $X = (x_{ij})_{m\times n}$, and the normalized data is $X' = (x_{ij}')_{m\times n}$. where x_{ij} and x_{ij}'represent the original and normalized value of the *j*-th sample of the *i*-th evaluation indicator, respectively.

Calculation Details:

For the two cases of the Fliggy crossover service ecosystem, we calculated the indicators from its overall granularity. Each case has pre-evolution and post-evolution indicator values, resulting in a total of 4 samples for each evaluation-level indicator in the Fliggy crossover service ecosystem. Thus, the normalized sample size is n=4. The normalization calculation process is as follows:

$$x_{ij}' = \frac{x_{ij} - Min(X)}{Max(X) - Min(X)}$$

Taking NPG value of the pre-evolution model in case 1 as an example, the normalized value can be calculated as $\frac{23-12}{24-12} = 0.916667$. We can obtain the normalized data as shown in Table 1.

Table 1 Normalized Result

guideline level	evaluation level	Case 1		Case 2		Case 1		Case 2	
		Pre-evolution	Post-evolution	Pre-evolution	Post-evolution	Pre-evolution	Post-evolution	Pre-evolution	Post-evolution
		x_{ij}				x_{ij}'			
Openness	NR	0	0	1	1	0	0	1	1
	ND	6	6	15	15	0	0	1	1
	NG	0	0	1	1	0	0	1	1
	OD	0	0	0	0	0	0	0	0
	TD	3	3	2	3	1	1	0	1
	DG	14	17	7	17	0.7	1	0	1
	ID	5	5	2	4	1	1	0	0.666667
Stability	SR	4	4	3	3	1	1	0	0
	DR	0.75	0.75	0.56	0.75	0.75	0.75	0.56	0.75
	SG	33	33	22	22	1	1	0	0
	DG	0.591	0.612	0.483	0.536	0.591	0.612	0.483	0.536
	SD	3	3	2	2	1	1	0	0
	RD	3	3	1	2	1	1	0	0.5
Activeness	ARG	0.104	0.113	0.145	0.166	0.104	0.113	0.145	0.166
	AOG	3.75	4.5	3.33	4.25	0.358974	1	0	0.786325
Extensibility	NEG	1	1	3	3	0	0	1	1
	NPG	23	24	12	17	0.916667	1	0	0.416667

Step 2:

The contribution of each evaluation indicator is:

$$C_i = \mathrm{k}\sum_{j=1}^{n} p_{ij} \ln p_{ij} + \theta, \tag{10}$$

where $p_{ij} \ln p_{ij}$ is the discrete degree of contribution between the *j*-th samples of the *i*-th indicator, $p_{ij} = \frac{x_{ij}{}' + \varepsilon}{\sum_{j=1}^{n}(x_{ij}{}' + \varepsilon)}$ indicates the *j*-th sample contribution of the *i*-th indicator. $\varepsilon = 0$ if $x_{ij}{}' > 0$, and $\varepsilon = 0.1$ if $x_{ij}{}' = 0$. $\sum_{j=1}^{n} p_{ij} \ln p_{ij}$ is the total contribution of all samples of the *i*-th indicator. $k = \frac{1}{\ln n}$, $\theta = 1$ is the adjustment factor, aiming to ensure that C_i is between [0,1].

Calculation Details:

Based on the normalization results in Table 1, we can obtain the value of p_{ij}, as shown in Table 2.

Table 2 p_{ij} Result

guideline level	evaluation level	Case 1		Case 2		Case 1		Case 2	
		Pre-evolution	Post-evolution	Pre-evolution	Post-evolution	Pre-evolution	Post-evolution	Pre-evolution	Post-evolution
		$x_{ij}{}'$				p_{ij}			
Openness	NR	0	0	1	1	0.045454545	0.045454545	0.454545455	0.454545455
	ND	0	0	1	1	0.045454545	0.045454545	0.454545455	0.454545455
	NG	0	0	1	1	0.045454545	0.045454545	0.454545455	0.454545455
	OD	0	0	0	0	0.25	0.25	0.25	0.25
	TD	1	1	0	1	0.322580645	0.322580645	0.032258065	0.322580645
	DG	0.7	1	0	1	0.25	0.357142857	0.035714286	0.357142857
	ID	1	1	0	0.666667	0.361445783	0.361445783	0.036144578	0.240963855
Stability	SR	1	1	0	0	0.454545455	0.454545455	0.045454545	0.045454545
	DR	0.75	0.75	0.56	0.75	0.266903915	0.266903915	0.199288256	0.266903915
	SG	1	1	0	0	0.454545455	0.454545455	0.045454545	0.045454545
	DG	0.591	0.612	0.483	0.536	0.265976598	0.275427543	0.217371737	0.241224122
	SD	1	1	0	0	0.454545455	0.454545455	0.045454545	0.045454545
	RD	1	1	0	0.5	0.384615385	0.384615385	0.038461538	0.192307692
Activeness	ARG	0.104	0.113	0.145	0.166	0.196969697	0.214015152	0.274621212	0.314393939
	AOG	0.358974	1	0	0.786325	0.159878188	0.445374952	0.044537495	0.350209364
Extensibility	NEG	0	0	1	1	0.045454545	0.045454545	0.454545455	0.454545455
	NPG	0.916667	1	0	0.416667	0.376712329	0.410958904	0.04109589	0.171232877

Thus, C_i is calculated as shown in Table 3:

Table 3 C_i Result

guideline level	evaluation level	Case 1		Case 2		C_i
		Pre-	Post-	Pre-	Post-	

		evolution	evolution	evolution	evolution	
		p_{ij}				
Openness	NR	0.045454545	0.045454545	0.454545455	0.454545455	0.280252
	ND	0.045454545	0.045454545	0.454545455	0.454545455	0.280252
	NG	0.045454545	0.045454545	0.454545455	0.454545455	0.280252
	OD	0.25	0.25	0.25	0.25	0
	TD	0.322580645	0.322580645	0.032258065	0.322580645	0.130286
	DG	0.25	0.357142857	0.035714286	0.357142857	0.133645
	ID	0.361445783	0.361445783	0.036144578	0.240963855	0.135413
Stability	SR	0.454545455	0.454545455	0.045454545	0.045454545	0.280252
	DR	0.266903915	0.266903915	0.199288256	0.266903915	0.0052
	SG	0.454545455	0.454545455	0.045454545	0.045454545	0.280252
	DG	0.265976598	0.275427543	0.217371737	0.241224122	0.002983
	SD	0.454545455	0.454545455	0.045454545	0.045454545	0.280252
	RD	0.384615385	0.384615385	0.038461538	0.192307692	0.150707
Activeness	ARG	0.196969697	0.214015152	0.274621212	0.314393939	0.012717
	AOG	0.159878188	0.445374952	0.044537495	0.350209364	0.16369
Extensibility	NEG	0.045454545	0.045454545	0.454545455	0.454545455	0.280252
	NPG	0.376712329	0.410958904	0.04109589	0.171232877	0.158493

Step 3:

The weight w_i of the i-th evaluation indicator can be calculated by:

$$w_i = \frac{C_i}{\sum_{i=1}^{m} C_i} \ , \tag{11}$$

where $\sum_{i=1}^{m} C_i$ is the total contribution value of all the evaluation indicators.

Then, the weight of the indicator of the corresponding guideline level can be calculated by using the additive of the contribution value of the indicator of the evaluation level:

$$w_k = \frac{H_k}{\sum_{i=1}^{m} C_i} \ , \tag{12}$$

where $H_k \ (k = 1, 2, \dots)$ is the contribution value of the indicator of the corresponding guideline level.

Calculation Details:

The result of w_i, H_k, and w_k can be calculated as shown in Table 4.

Table 4 w_i, H_k, and w_k Result

guideline level	evaluation level	C_i	w_i	H_k	w_k
Openness	NR	0.280252	0.098165	1.240099	0.434376277
	ND	0.280252	0.098165		
	NG	0.280252	0.098165		
	OD	0	0		
	TD	0.130286	0.045636		

	DG	0.133645	0.046812		
	ID	0.135413	0.047432		
Stability	SR	0.280252	0.098165	0.999645	0.350150995
	DR	0.0052	0.001821		
	SG	0.280252	0.098165		
	DG	0.002983	0.001045		
	SD	0.280252	0.098165		
	RD	0.150707	0.052789		
Activeness	ARG	0.012717	0.004454	0.176408	0.061791221
	AOG	0.16369	0.057337		
Extensibility	NEG	0.280252	0.098165	0.438745	0.153681508
	NPG	0.158493	0.055516		

Step 4:

Thus, the composite index of the sustainability of the ecosystem can be measured by F:

$$F = \sum_{i=1}^{t} w_k \times \left(\sum_{j=1}^{r} x_{ki} \times w_{ki}\right), \quad (13)$$

Calculation Details:

The result of $x_{ki} \times w_{ki}$ can be calculated as shown in Table 5.

Table 5 $x_{ki} \times w_{ki}$

guideline level	evaluation level	Case 1		Case 2		w_i/w_{ki}	Case 1		Case 2	
		Pre-evolution	Post-evolution	Pre-evolution	Post-evolution		Pre-evolution	Post-evolution	Pre-evolution	Post-evolution
		x_{ij}'/x_{ki}					$x_{ki} \times w_{ki}$			
Openness	NR	0	0	1	1	0.098165	0	0	0.098165	0.098165
	ND	0	0	1	1	0.098165	0	0	0.098165	0.098165
	NG	0	0	1	1	0.098165	0	0	0.098165	0.098165
	OD	0	0	0	0	0	0	0	0	0
	TD	1	1	0	1	0.045636	0.045636	0.045636	0	0.045636
	DG	0.7	1	0	1	0.046812	0.032769	0.046812	0	0.046812
	ID	1	1	0	0.666667	0.047432	0.047432	0.047432	0	0.031621
Stability	SR	1	1	0	0	0.098165	0.098165	0.098165	0	0
	DR	0.75	0.75	0.56	0.75	0.001821	0.001366	0.001366	0.00102	0.001366
	SG	1	1	0	0	0.098165	0.098165	0.098165	0	0
	DG	0.591	0.612	0.483	0.536	0.001045	0.000618	0.00064	0.000505	0.00056
	SD	1	1	0	0	0.098165	0.098165	0.098165	0	0
	RD	1	1	0	0.5	0.052789	0.052789	0.052789	0	0.026395
Activeness	ARG	0.104	0.113	0.145	0.166	0.004454	0.000463	0.000503	0.000646	0.000739
	AOG	0.358974	1	0	0.786325	0.057337	0.020582	0.057337	0	0.045085
Extensibility	NEG	0	0	1	1	0.098165	0	0	0.098165	0.098165
	NPG	0.916667	1	0	0.416667	0.055516	0.05089	0.055516	0	0.023132

The result of $\sum_{j=1}^{r} x_{ki} \times w_{ki}$ be calculated as shown in Table 6.

Table 6 $\sum_{j=1}^{r} x_{ki} \times w_{ki}$

guideline level	evaluation level	Case 1		Case 2		Case 1		Case 2	
		Pre-evolution	Post-evolution	Pre-evolution	Post-evolution	Pre-evolution	Post-evolution	Pre-evolution	Post-evolution
		$x_{ki} \times w_{ki}$				$\sum_{j=1}^{r} x_{ki} \times w_{ki}$			
Openness	NR	0	0	0.098165	0.098165	0.125837	0.139881	0.2944957	0.418566
	ND	0	0	0.098165	0.098165				
	NG	0	0	0.098165	0.098165				
	OD	0	0	0	0				
	TD	0.045636	0.045636	0	0.045636				
	DG	0.032769	0.046812	0	0.046812				
	ID	0.047432	0.047432	0	0.031621				
Stability	SR	0.098165	0.098165	0	0	0.349268	0.34929	0.0015247	0.028321
	DR	0.001366	0.001366	0.00102	0.001366				
	SG	0.098165	0.098165	0	0				
	DG	0.000618	0.00064	0.000505	0.00056				
	SD	0.098165	0.098165	0	0				
	RD	0.052789	0.052789	0	0.026395				
Activeness	ARG	0.000463	0.000503	0.000646	0.000739	0.021046	0.05784	0.0006459	0.045825
	AOG	0.020582	0.057337	0	0.045085				
Extensibility	NEG	0	0	0.098165	0.098165	0.05089	0.055516	0.0981652	0.121297
	NPG	0.05089	0.055516	0	0.023132				

The result of F can be calculated as shown in Table 7.

Table 7 F

guideline level	Case 1		Case 2		w_k
	Pre-evolution	Post-evolution	Pre-evolution	Post-evolution	
	$\sum_{j=1}^{r} x_{ki} \times w_{ki}$				
Openness	0.125837	0.434376277	0.2944957	0.418566	0.434376277
Stability	0.349268	0.34929	0.0015247	0.028321	0.350150995
Activeness	0.021046	0.05784	0.0006459	0.045825	0.061791221
Extensibility	0.05089	0.055516	0.0981652	0.121297	0.153681508
F	0.186078	0.195171	0.143582	0.213204142	-