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Dynamic Simulation Model for Sustainable Municipality Development in Vidzeme Region, Latvia

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***Abstract.* Authors in this research paper publish the results of system dynamic simulation modelling in the field of sustainable development planning, monitoring and evaluation for all 26 Latvia Vidzeme region municipalities. As the most notable research outcome, authors created original socio-technical system dynamic simulation model in STELLA modelling environment valid for sustainable development evaluation purposes.**

After successful verification and validation process of this model authors reached the significant results for improved methodology of dynamic systems evaluation process reliability of sustainable development in Vidzeme region municipalities. Methodology, proposed by authors roots into the quantitative statistical data analysis and system dynamic process simulation modelling.

Keywords: sustainable development, modelling, system dynamics, municipality.

I. INTRODUCTION

Vidzeme region municipalities in Latvia still use very limited arsenal of scientifically based and reliable scientific methods and tools for planning and evaluation of sustainable development process within their administrative territories. It creates a situation when formally achieved results of municipalities long-term sustainable development planning and evaluation are not fully reliable because all analytic outcomes and results are created mostly by use of simplified pre-designed templates and political decisions. In many cases, there are used simplified qualitative research methodologies in the form of general questionnaires and non-structured interviews, but very limited are applications of quantitative statistical data analysis or algorithmic socio-technical systems dynamic process simulation modelling.

Sustainable regional development has been defined by researchers in various ways but the core components in the most of definitions are almost the same: sustainable economy, sustainable society and sustainable environment [1, 2, 3, 4, 5].

From Year 2009 In Latvia came into the legal force new administrative territorial division of municipalities. Therefore, Vidzeme region is now divided into 26 municipalities: 25 rural districts and 1 city municipality (Fig. 1).

As stated in Latvian legislation all municipalities are obliged to develop determined set of sustainable development strategic planning documents. The highest priority document is “Sustainable development strategy for X municipality”. These strategies had been developed by all municipalities in Vidzeme region for period of 20-25 forthcoming years. The operative level sustainable development planning documents are “Development program for X municipality”. These programs had been developed for all municipalities in Vidzeme region for 5-7 forthcoming years [6]. Accordingly, authors stated the main aim of research as follows: to create socio-technical dynamic simulation model for sustainable development evaluation process in Vidzeme region municipalities.

Fig. 1. Map of Vidzeme region municipalities [6]

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Detailed studies of sustainable development strategies and planning documents in all 26 municipalities provided the basic framework and an input data set for further analysis and with purpose to create socio-technical dynamic simulation model for sustainability evaluations.

II. METHODOLOGY

To be sure that the development process of municipality proceeds in a sustainable way, it is necessary to keep steady balance among various economic, social and environmental factors. One of the leading sustainable development determination and evaluation methodology in the world nowadays is “Triple Bottom Line” (TBL) framework methodology analyzed by many researchers all over the world [7, 8, 9, 10, 11].

At the first stage of this research TBL method was applied an adapted to serve specific objectives of research (Fig. 2).

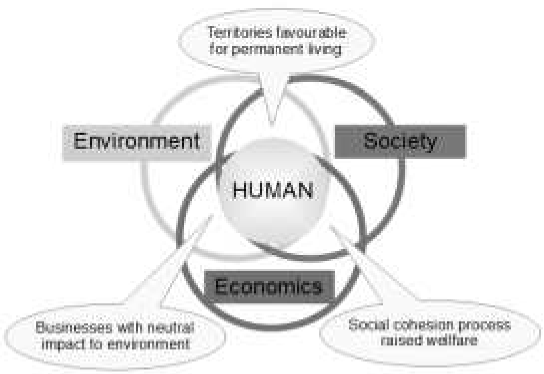

Fig. 2. Theoretical framework of applied “Triple Bottom Line“ methodology

At the second research stage all existing sustainable development systems for 26 municipalities in Vidzeme region had been matched on their compliance with “Triple Bottom Line” methodology theoretical framework (Table I).

Table I
Compatibility of municipality sustainable development systems with TBL methodology framework

Municipality	**Fully TBL**	**Partially TBL**	**Undefined TBL**
Aluksne			undefined
Amata		partially	
Ape	fully		
Beverina	fully		
Burtnieki		partially	
Cesvaine		partially	
Cēsis	fully		
Ergli		partially	
Gulbene	fully		
Jaunpiebalga		partially	
Koceni		partially	
Ligatne	fully		
Lubana	fully		
Madona	fully		
Mazsalaca		partially	
Naukseni	fully		
Pargauja	fully		
Priekuli		partially	
Rauna	fully		
Rujiena		partially	
Smiltene	fully		
Strenci		partially	
Valka		partially	
Varaklani		partially	
Vecpiebalga	fully		
Valmiera		partially	

As drawn from analysis above in 25 from 26 municipalities their already published sustainable development strategies indicates systemic frameworks fully or partially compatible with “Triple Bottom Line” methodology theoretical framework. In partially compatible frameworks there are minimum 67% percent compatibility (at least 2 from 3 TBL dimensions are equal) and maximum 75% percent match (3 from total 4 indicated dimensions are equal to TBL). At this stage, had been proved that choice of specific TBL methodology is optimal decision for further statistical data analysis and dynamic simulation modelling.

The third stage of research covered selection of appropriate system dynamics simulation modelling tools. General theories of system dynamics describe that for such complicated and integrated dynamic systems as municipalities, intensive use of socio-technical systems modelling is one of the optimal solutions [12, 13, 14, 15]. In this research, as specific tool for modelling purposes was chosen STELLA (ver. 9.0.3) modelling software.

In the fourth stage of research statistical data retrieval and analysis issues had been systematized. Only data from official databases of Latvian Central Statistical Bureau, Office of Citizenship and Migration Affairs, Ministry of Environmental Protection and Regional Development, State Employment Agency, Treasury Republic of Latvia, Vidzeme Planning Region and respective municipalities were used for data statistical analysis.

Sustainable development evaluation process in municipalities can be characterized as trend analysis thus as the most appropriate statistical analysis method were used “trend” and “forecast” functions from PSPP statistical data analysis tool (Fig. 3).

Period	Number of inhabitants			
1	19358			
2	19121			
3	18806			
4	18501			
5	18020			
10		Equation	Forecast	Trend
11			16124	
12			15795	
13			15465	
20			**13158**	13158

Fig. 3. Number of inhabitants forecast (trend) analysis (Aluksne)

At the final research stage were selected 9 specific factors (3 from economic dimension influence factors, 3 from social dimension influence factors and 3 from environmental dimension influence factors) for socio-technical modelling purposes. Then were created theoretical sustainability evaluation model to be implemented in STELLA modelling software (Fig. 4).

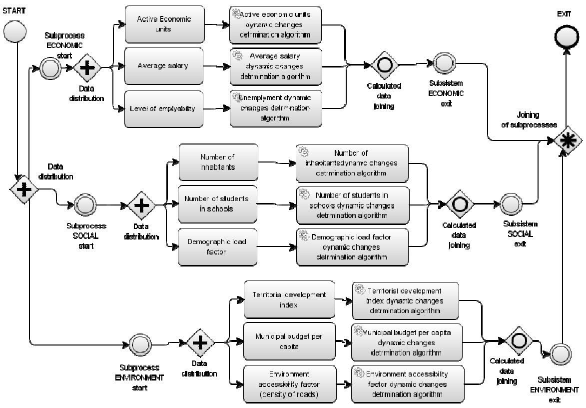

Fig. 4. Theoretical sustainability evaluation model (in BPMN 2.0 notation)

As one of the limitations for this model could be mentioned still insufficient incoming data flow from statistical databases because new administrative structures for Vidzeme region municipalities were created only in Year 2009. That means, that indicators and factors in all three dimensions have maximum 6 years long previous incoming data stream and predicted trends calculated for the next 15 years. Of course, it concerns only data analysis and produced results reliability but nor the model structure or data management options.

III. RESULTS AND DISCUSSION

From all analysed sustainable development strategies, development programs and special territorial planning documents of Vidzeme region municipalities (in total 56 documents) there were retrieved 484 indicators at least once mentioned in these documents with purpose to evaluate sustainability performance. From total number, there were selected 178 unique indicators but only 42 indicators which are measurable within calendar year interval. From them 31 indicators are valid and specific for all 26 local municipalities in Vidzeme region. Finally, there are only 27 indicators, mentioned in strategies and planning documents as minimum 3 times. These 27 indicators were used in this research for test modelling purposes. Most of retrieved quantitative indicators belong to the economic dimension and/or social dimension but just few of them has connection with environmental dimension. Accordingly, there were assigned higher specific weight (0,5 from 1,0 in total) to economic dimension indicators for modelling purposes. Social dimension indicators have medium assigned specific weight (0,3 from 1,0 in total) and environmental dimension indicators have lowest assigned specific weight (0,2 from 1,0 in total).

After multiply test runs with different sets of indicators, authors input into the final socio-technical simulation model version (ver 1.0) the following ones:

[E1] Number of active economic units registered in municipality (dominating economic dimension);
[E2] Average salary of people declared in municipality (dominating economic dimension);
[E3] Unemployment rate of people declared in municipality (dominating economic dimension);
[S1] Number of inhabitants in municipality (dominating social dimension);
[S2] Number of pupils and students in schools located in municipality (dominating social dimension);
[S3] Demographic load factor per municipality (dominating social dimension);
[V1] Territorial development index of municipality (dominating environmental and economic dimensions);
[V2] Municipal budget per capita (dominating environmental, economic and social dimensions);
[V3] Environment accessibility (density of roads) (dominating environmental and social dimension).

All selected indicators are sufficiently backed up with reliable data series from last 4-7 years in official statistical databases. Some other significant indicators for environmental dimension evaluation was impossible to implement into proposed model (like amount EU, state and local budget funds allocated specifically for environmental programs or number of households with direct access to the centralized sewage and waste management systems) due to lack of sufficient data flows for all 26 municipalities of Vidzeme region.

Complete socio-technical system dynamic simulation model in STELLA modelling environment (Fig. 5) consists from 3 main processes and 9 sub processes where total value of sustainability growth trend is calculated as a single trendline.

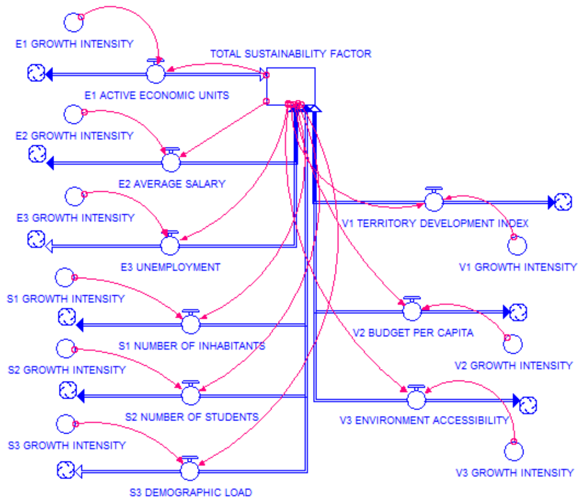

Fig. 5. Sustainability dynamic simulation model (in STELLA modelling environment)

At the next model development stage, all 26 forecasted sustainability growth trends for municipalities of Vidzeme region were calculated by use of differential equitation:

TOTAL_SUSTAINABILITY_FACTOR(t) = TOTAL_SUSTAINABILITY_FACTOR(t - dt) + (E1_ACTIVE_ECONOMIC_UNITS + E2_AVERAGE_SALARY + V1_TERRITORY_DEVELOPMENT_INDEX + V2_BUDGET_PER_CAPITA + V3_ENVIRONMENT_ACCESSIBILITY + S2_NUMBER_OF_STUDENTS + S1_NUMBER_OF_INHABITANTS - E3_UNEMPLOYMENT_RATE - S3_DEMOGRAPHIC_LOAD) * dt
INIT TOTAL_SUSTAINABILITY_FACTOR = 100

With 7 predefined inflows (higher values corresponds to better growth trends):

(1) E1_ACTIVE_ECONOMIC_UNITS = TOTAL_SUSTAINABILITY_FACTOR*E1_GROWTH_INTENSITY*50/3/100
(2) E2_AVERAGE_SALARY = TOTAL_SUSTAINABILITY_FACTOR*E2_GROWTH_INTENSITY*50/3/100
(3) S1_NUMBER_OF_INHABITANTS = TOTAL_SUSTAINABILITY_FACTOR*S1_GROWTH_INTENSITY*30/3/100
(4) S2_NUMBER_OF_STUDENTS = TOTAL_SUSTAINABILITY_FACTOR*S2_GROWTH_INTENSITY*30/3/100
(5) V1_TERRITORY_DEVELOPMENT_INDEX = TOTAL_SUSTAINABILITY_FACTOR*V1_GROWTH_INTENSITY*20/3/100
(6) V2_BUDGET_PER_CAPITA = TOTAL_SUSTAINABILITY_FACTOR*V2_GROWTH_INTENSITY*20/3/100
(7) V3_ENVIRONMENT_ACCESSIBILITY = TOTAL_SUSTAINABILITY_FACTOR*V3_GROWTH_INTENSITY*20/3/100

And with 2 predefined outflows (lower values corresponds to better growth trends):

(1) E3_UNEMPLOYMENT = TOTAL_SUSTAINABILITY_FACTOR*E3_GROWTH_INTENSITY*50/3/100
(2) S3_DEMOGRAPHIC_LOAD = TOTAL_SUSTAINABILITY_FACTOR*S3_GROWTH_INTENSITY*30/3/100

As initial value in the beginning of Year 2016 were given 100 sustainability factor units and simulated further potential positive or negative growth trends and calculated trendline specific sustainability factor values within period from Year 2016 till Year 2030 (15 years, in line with the period designated in sustainable development strategies of municipalities). If final total value of sustainability factor goes below 100 units then this municipality had been regarded as *"unsustainable"* (there were no such cases in Vidzeme region municipalities). If final total value of sustainability factor reached level from 100 till 250 units then this municipality had been evaluated as *"low sustainability prospective"*. If final total value of sustainability factor reached level from 250 till 750 units then this municipality had been evaluated as *"low/medium sustainability prospective"*. If final total value of sustainability factor reached level from 250 till 750 units then this municipality had been evaluated as *"medium sustainability prospective"*. If final value of sustainability factor reached level from 750 till 1250 units then this municipality had been evaluated as *"medium/high sustainability prospective"*. If final total value of sustainability factor reached level above 1250 units then this municipality had been evaluated as *"high sustainability prospective"*.

The weakest sustainability performer in Vidzeme region is Jaunpiebalga municipality as drawn up from simulation modelling results (Fig. 6, 7, 8). This municipality demonstrates total sustainability factor growth score corresponding to "low/medium sustainability prospective" (approx. 500 units).

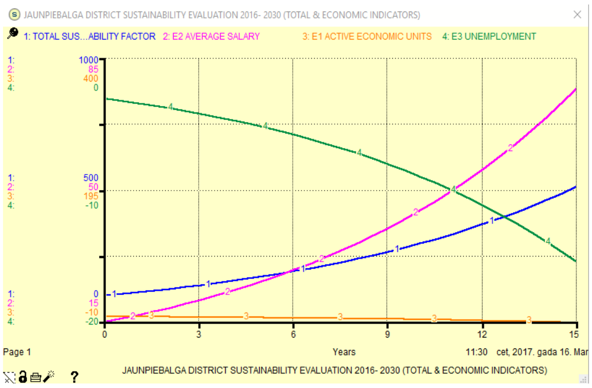

Fig. 6. Jaunpiebalga municipality sustainability evaluation (total & economic dimensions' evaluation)

Jaunpiebalga municipality in economic sustainability dimension indicates positive trends for "unemployment" factor (decrease) and "average salary" factor (increase) but negative trend for "active economic units" factor (decrease).

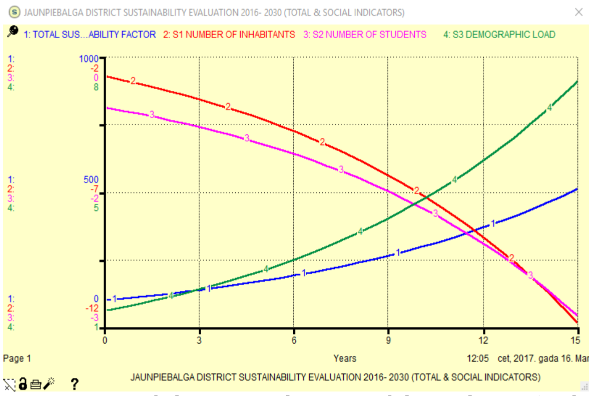

Fig. 7. Jaunpiebalga municipality sustainability evaluation (total & social dimensions' evaluation)

Jaunpiebalga municipality in social sustainability dimension demonstrates only negative trends over time for all factors- "number of inhabitants" factor (decrease), "number of students in schools" factor (decrease) and "demographic load" factor (increase).

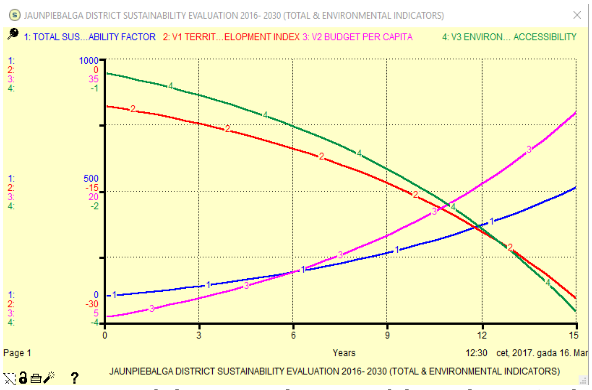

Fig. 8. Jaunpiebalga municipality sustainability evaluation (total & environmental dimensions' evaluation)

Jaunpiebalga municipality in environmental sustainability dimension displays positive trend for "budget per capita" factor (increase) but negative trends for "territory development index" factor (decrease) and "environment accessibility" factor (decrease).

Data analysis discovers the major risk of sustainability for Jaunpiebalga municipality as decreasing sustainability for social dimension. Designed simulation model for all social factors compounded has specific weight of only 30% from total 100% therefore economic and environmental dimensions compensate negative social dimension and total sustainability factor value is still positive and fits into "low/medium sustainability prospective" group.

In comparison, further the same analysis provided for the best performer in Vidzeme region- Valmiera City municipality regarding STELLA dynamic simulation modelling results (Fig. 9, 10, 11). This is only one municipality in Vidzeme region which demonstrates evaluated sustainability growth trend as "high sustainability prospective".

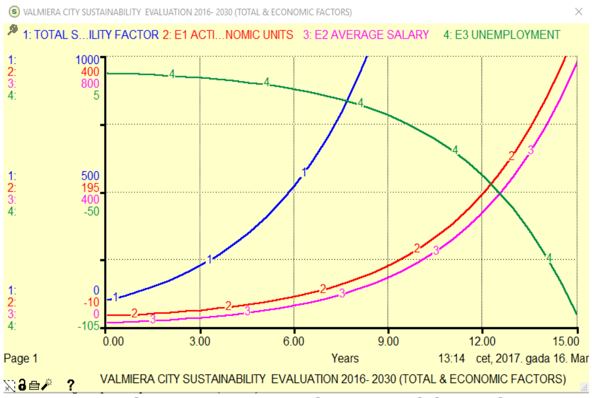

Fig. 9. Valmiera City municipality sustainability evaluation (total & economic dimensions' evaluation)

Valmiera City municipality in economic sustainability dimension indicates extremely positive trends for all three selected factors- "active economic units" factor (increase), "unemployment" factor (decrease) and "average salary" factor (increase).

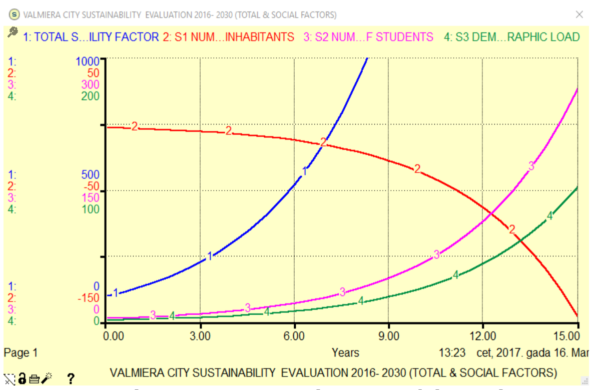

Fig. 10. Valmiera City municipality sustainability evaluation (total & social dimensions' evaluation)

Valmiera City municipality in social sustainability dimension demonstrates negative trends over time for two factors- “number of inhabitants” factor (decrease) and “demographic load” factor (increase) but positive changes for factor “number of students in schools” factor (increase).

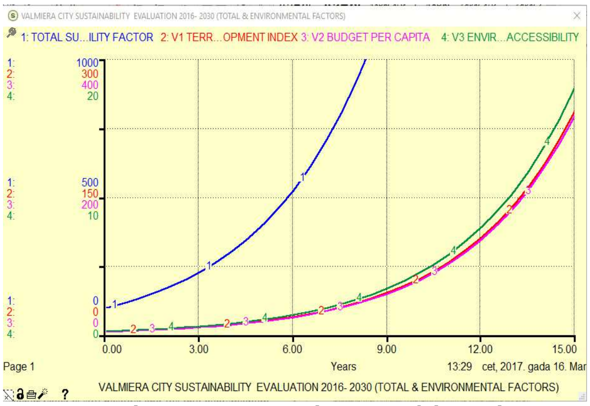

Fig. 11. Valmiera City municipality sustainability evaluation (total & environmental dimensions’ evaluation)

Valmiera City municipality in environmental sustainability dimension demonstrates positive trends for all three factors “territory development index” factor (increase), “budget per capita” factor (increase) and “environment accessibility” factor (increase).

In fact, specific real situation analysis shows that sustainable development situation in Valmiera is even better than it is calculated from official statistics because number of permanent inhabitants in the City is growing, despite official statistics which relies only on data about number of officially declared inhabitants. Incoming flow of young people at the working age also in positive manner influences another still negative factor for Valmiera City municipality, respectively, “demographic load”.

Similar analysis with created STELLA dynamic simulation model was provided for all 26 Vidzeme region municipalities. The overall results of sustainable development trends in Vidzeme are mostly positive (TABLE II). There are no municipalities in the area with “unsustainable” or “low sustainability” prospective. Seven municipalities in Vidzeme region have evaluation “low/medium sustainability prospective”, 14 municipalities have evaluation “medium sustainability prospective”, four municipalities have evaluation “medium/high sustainability prospective” and one- Valmiera City municipality has evaluation “high sustainability prospective”.

Table II
Evaluation results of Vidzeme region municipalities sustainable development prospective

Municipality	Low sustainability prospective	Medium sustainability prospective	High sustainability prospective
Aluksne	NO	**YES**	NO
Amata	NO	**YES**	**YES**
Ape	NO	**YES**	NO
Beverina	NO	**YES**	NO
Burtnieki	NO	**YES**	NO
Cesvaine	NO	**YES**	NO
Cēsis	**YES**	**YES**	NO
Ergli	NO	**YES**	NO
Gulbene	NO	**YES**	NO
Jaunpiebalga	**YES**	**YES**	NO
Koceni	NO	**YES**	**YES**
Ligatne	NO	**YES**	NO
Lubana	**YES**	**YES**	NO
Madona	NO	**YES**	NO
Mazsalaca	**YES**	**YES**	NO
Naukseni	NO	**YES**	NO
Pargauja	NO	**YES**	NO
Priekuli	NO	**YES**	**YES**
Rauna	NO	**YES**	NO
Rujiena	**YES**	**YES**	NO
Smiltene	NO	**YES**	**YES**
Strenci	**YES**	**YES**	NO
Valka	NO	**YES**	NO
Varaklani	**YES**	**YES**	NO
Vecpiebalga	NO	**YES**	NO
Valmiera	NO	NO	**YES**

IV. CONCLUSION

Produced results by new sustainable development evaluation dynamic simulation model for Vidzeme region municipalities are close to results published by other researchers dealing with GDP per capita or GDP per sq. km growth analysis in Latvia [6, 16].

Current Latvia state policy allows full freedom for municipalities in their sustainable development strategic planning, monitoring and evaluation thus now we have 26 completely different strategies in Vidzeme region with incompatible methodologies and indicators. There should be accepted unified sustainable development strategic planning methodology framework at the central government (ministry) level.

Designed dynamic simulation model has very high eventual scalability and elasticity level for further adaptations and improvements, for example, it is easily possible to replace, add or remove sustainability indicators or add scripts for automatic data retrieval from official statistical databases.

V. ACKNOWLEDGMENTS

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