

Embedded Software Memory Size Estimation using COSMIC: A Case Study



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Agenda



- **Reminders on ECU**
- **What is at stake?**
- **Background**
- **Research question**
- **Case study**
 - Data collection
 - Data analysis and results
- **Validity threats**
- **Conclusions and Future work**



Reminders



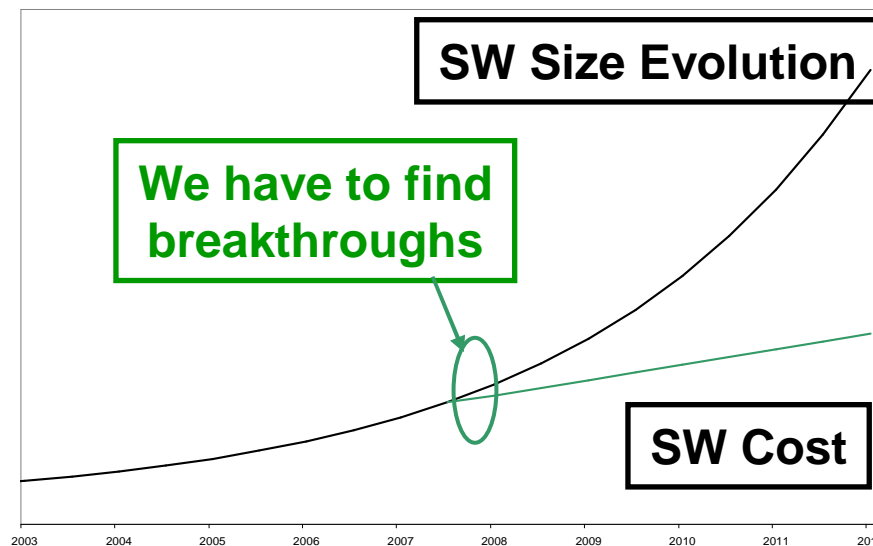
- In a car, most of major functionalities are provided through dedicated ECUs connected through a communications network.
- What is an ECU?
 - An ECU (Engine Control Unit) is composed of Hardware and Software.



What is at stake?



- In automotive industry, more and more functionalities are provided through dedicated ECUs (Engine Control Units).



- New automotive functionalities → More and more embedded software in a car.
- Optimize the memory space is essential for developing cost effective embedded systems.



Industrial needs



- **The ECU's hardware choice is made very early when choosing the ECU development supplier.**
- **ECUs should be designed to have sufficient memory (ROM , RAM , E2Prom).**
- **Traditionally ROM and RAM sizes are estimated by using expert opinion method.**
- **Major risks:**
 - **Over-estimation of the memory sizes → Hardware over-dimensioned → Unnecessary costs.**
 - **Under-estimation of the memory sizes → Risk of increasing the car development schedule, supplementary costs.**

The Problem

- **Early and reliable ECUs memory size estimation is essential for automotive industry!**





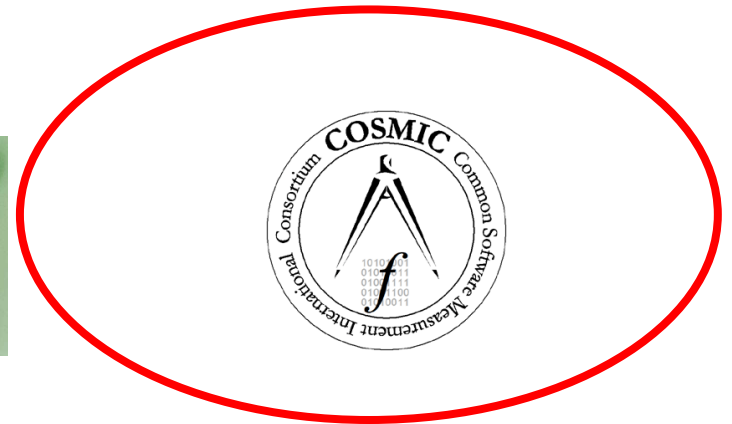
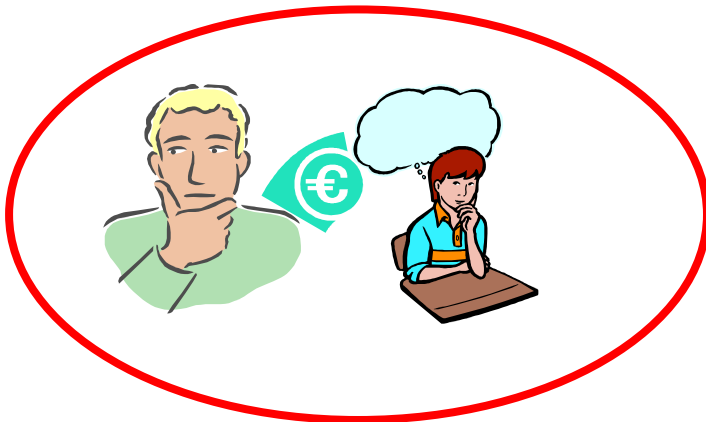
A New Approach – Using COSMIC FP

- **COSMIC is a 2nd generation FSM method designed to measure real-time embedded systems**
- **Toivonen (2002) proposed a measure for software memory efficiency (CFP/Mem.size) in mobile terminals**
- **Lind and Heldal (2008, 2009, 2010) conducted experiments in GM and developed a model to estimate the memory space required for ECUs from CFP**
- **Gencel, Heldal and Lind (2009) compared the relationship CFP-SLOC to CFP-Bytes**
- **Although SLOC-CFP relationship was weak, CFP-Bytes showed significantly strong relationship**



Renault - Research Question

- Is the COSMIC functional size (in CFP) a more reliable measure to predict the ECU memory size in real time embedded software than the traditional expert opinion methods?



Case Study

- **The ECU's choice.**
- **The chosen ECU was the BCM: Body Control Module.**
- **The BCM is typically in charge to manage lights, doors locking, and so on.**
- **BCM was chosen because:**
 - COSMIC had been already used on costs predictions for BCM → COSMIC functional sizes were available.
 - ROM, RAM, E2PROM measurements were available.
 - Very high level expert judgments were available for BCM.



Case Study

Data Collection

- **Data collected on 19 functions of the BCM designed by Renault and coded by one of its suppliers**
- **The BCM functions were developed using the same programming language, compiler and development method.**
- **Two experienced measurers who have been using COSMIC for the last two years in Renault made the functional size measurements.**



Functional Sizes and Actual Memory Sizes for Functions

Function	CFP	Actual Memory Size (kB)				
		ROM	RAM	E2P	RAM+E2P	CFP/ROM+RAM+E2P (kB)
<i>function 2</i>	53	2.30	0.08		0.08	22.3
<i>function 4</i>	259	12.50	0.17	0.02	0.18	20.4
<i>function 10</i>	66	3.81	0.09		0.09	16.9
<i>function 15</i>	22	1.02	0.04		0.04	20.8
<i>function16</i>	73	3.81	0.09		0.09	18.7
<i>function 17</i>	748	32.96	0.58	0.16	0.73	22.2
<i>function 18</i>	90	31.08	0.63	0.13	0.75	2.8
<i>function 21</i>	7	0.58	0.07	0.03	0.10	10.2
<i>function 22</i>	8	0.85	0.04		0.04	9.0
<i>function 23</i>	34	1.79	0.04		0.04	18.7
<i>function 24</i>	39	2.14	0.05		0.05	17.8
<i>function 25</i>	45	4.96	0.53		0.53	8.2
<i>function 26</i>	54	2.51	0.07	0.02	0.08	20.8
<i>function 27</i>	57	1.97	0.08	0.02	0.11	27.5
<i>function 28</i>	91	4.72	0.14		0.14	18.7
<i>function 29</i>	110	4.01	0.07		0.07	27.0
<i>function 30</i>	136	5.71	0.12		0.12	23.3
<i>function 31</i>	155	10.50	0.16	0.02	0.18	14.5
<i>function 32</i>	157	5.14	0.10	0.02	0.11	29.9

Case Study

Data Analysis

- **The strength of the relationship between CFP and ROM size (kB) investigated (Correl. Coeff, R^2)**
- **The outlier functions identified and excluded**
- **A linear estimation model developed:**
 - Chose 10 functions randomly out of 19 to build the model
 - Performed linear regression analysis on this sub-dataset
- **The memory size estimates obtained by expert opinion methods were compared to estimates obtained by the estimation model**



Case Study (step 1)

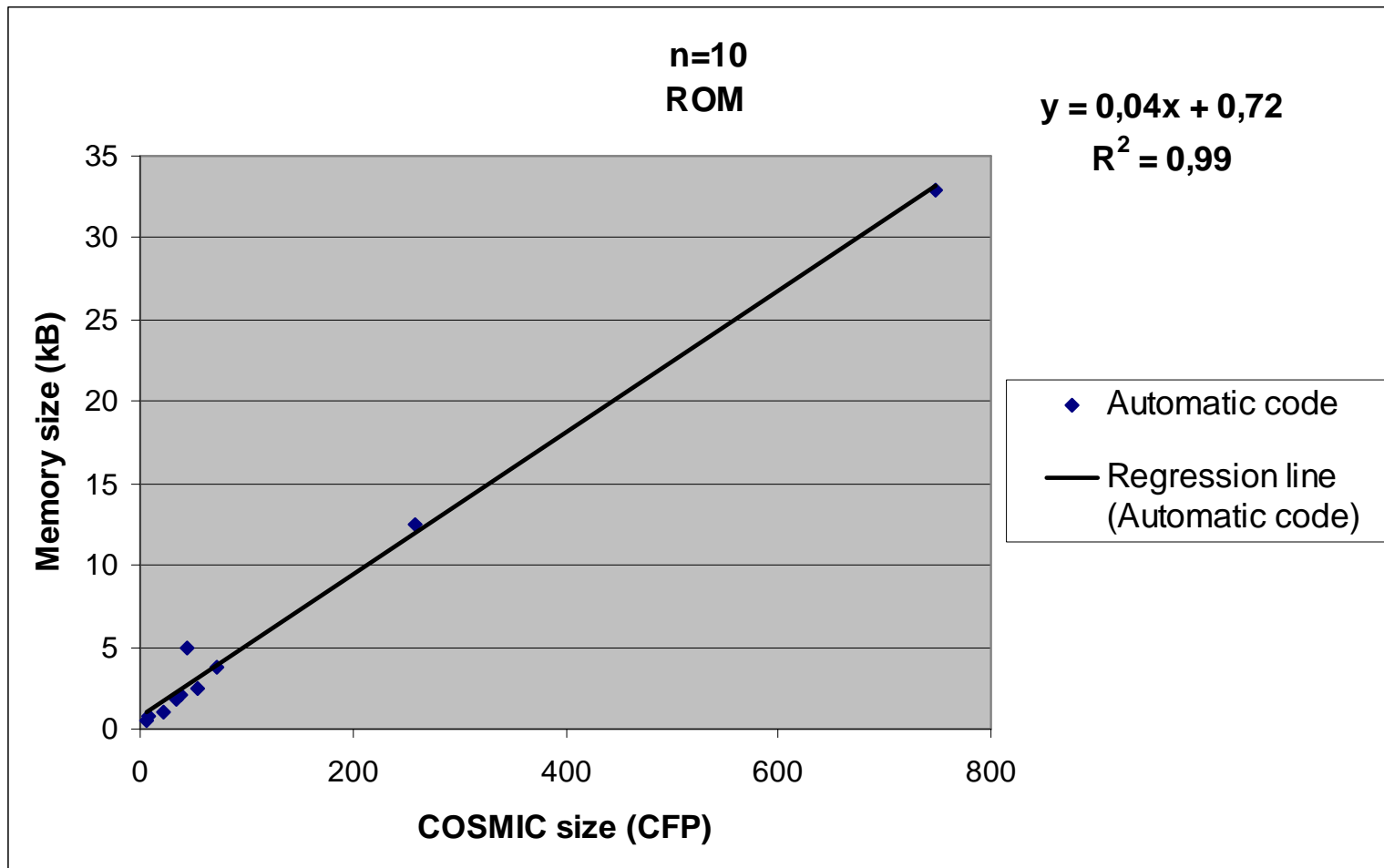
Data Analysis

- **Linear estimation models (CFP / Bytes) were developed:**
 - Chose 10 functions randomly out of 19 to build the model
 - Performed linear regression analysis on this sub-dataset

- **2 Linear estimation models were developed:**
 - → A linear estimation model for ROM
 - → A linear estimation model for RAM+E2PROM



Fig 1. CFP vs ROM size (kB) (for subset, n =10)



Comparison of the Memory Size Estimates and Residual Errors for the Case Functions

Function	Actual memory size (kB)		COSMIC Based Memory Size Estimates (kB)		Renault Experts Memory Size Estimates (kB)		Sup.Exp. Mem Est. (kB)	% Residual (COSMIC)		% Residual (Renault Experts)		% Resid. (Suppl. Exp.)
	ROM	RAM +E2P	ROM	RAM+E2P	ROM	RAM	ROM	ROM	RAM+E2P	ROM	RAM	ROM
2	2.30	0.08	3.02	0.13	0.50	0.01	0.49	31.4	65.7	-78.1	-91.0	-78.7
4	12.50	0.18	11.96	0.30	25.78	0.37	25.20	-4.3	63.5	106.3	104.3	101.6
10	3.81	0.09	3.58	0.14	3.51	1.73	3.42	-6.0	44.6	-7.8	1729	-10.3
15	1.02	0.04	1.67	0.10			19.73	63.7	185.9			1831
16	3.81	0.09	3.89	0.14	5.99	0.11	5.86	1.9	52.3	57.0	20.8	53.7
17	32.96	0.73	33.18	0.70	27.08	0.20	26.46	0.7	-4.3	-17.8	-73.4	-19.7
21	0.58	0.10	1.02	0.09	0.17	0.03	0.20	74.9	-13.3	-70.6	-69.2	-66.6
22	0.85	0.04	1.06	0.09	0.51	0.03	0.49	25.9	127.6	-39.8	-30.0	-42.3
23	1.79	0.04	2.19	0.11	2.08	0.04	2.05	22.7	214.2	16.1	5.6	14.8
24	2.14	0.05	2.41	0.11			2.15	12.6	109.6			0.4
25	4.96	0.53	2.67	0.12	5.55	1.22	5.37	-46.1	-77.5	11.9	130.1	8.3
26	2.51	0.08	3.06	0.13	4.72	0.10	4.59	22.0	51.3	87.9	16.3	82.9
27	1.97	0.11	3.19	0.13	3.87	0.07	3.81	62.3	22.8	96.6	-35.2	93.6
28	4.72	0.14	4.67	0.16	7.39	0.12	7.23	-1.1	15.4	56.6	-10.0	53.2
29	4.01	0.07	5.49	0.17	4.72	0.10	4.59	37.1	140.1	17.7	35.1	14.6
30	5.71	0.12	6.62	0.20	5.72	0.11	5.57	16.0	61.1	0.2	-11.3	-2.4
31	10.50	0.18	7.44	0.21	10.99	0.16	10.74	-29.1	17.3	4.7	-12.0	2.3
32	5.14	0.11	7.53	0.21	5.59	0.07	5.47	46.4	87.5	8.6	-39.7	6.3

Case Study (step 2)

Data Analysis

- The strength of the relationship between CFP and ROM size (kB) investigated (Correl. Coeff, R^2)
- The outlier functions identified and excluded



Fig 2. CFP versus ROM size (kB)

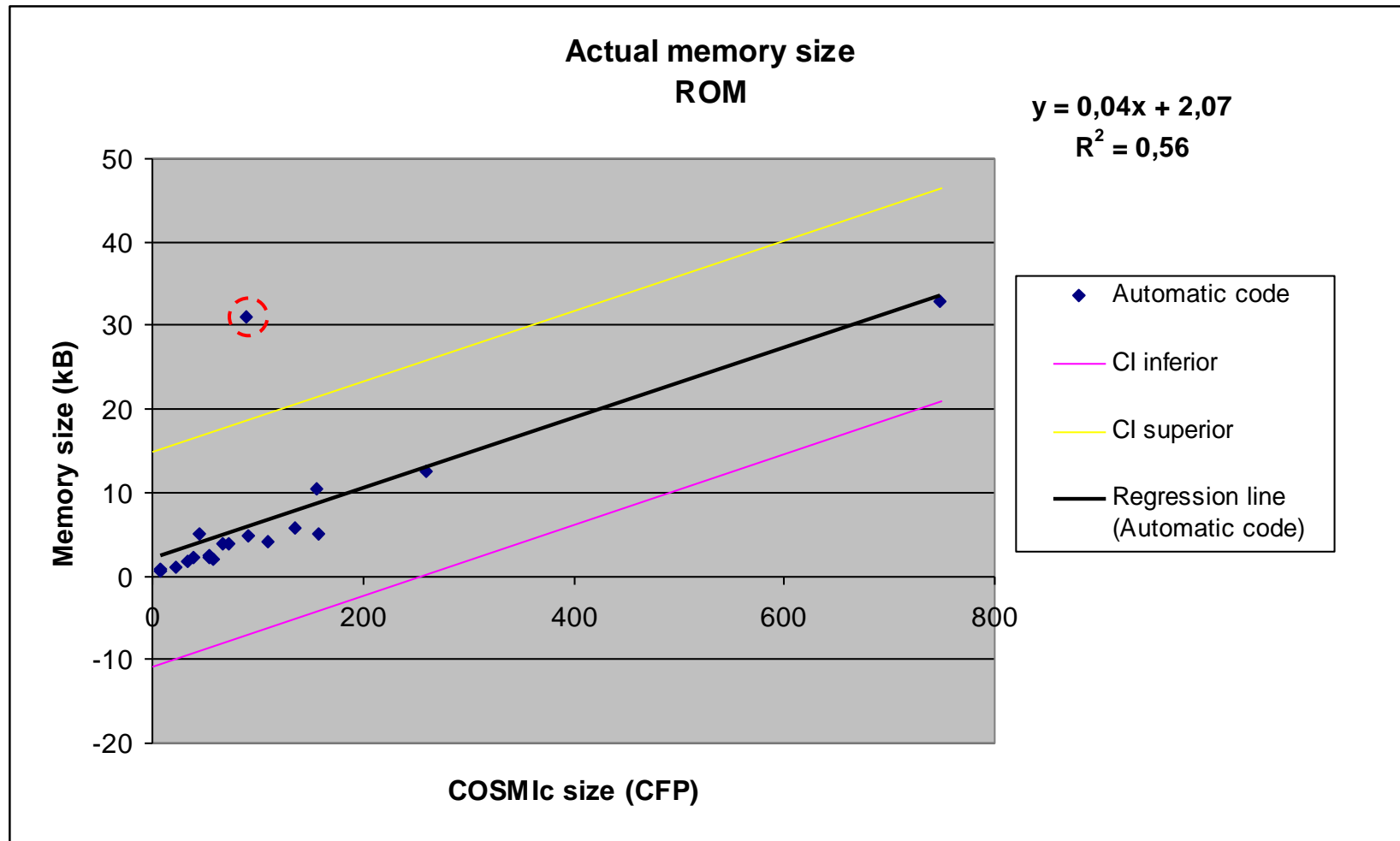
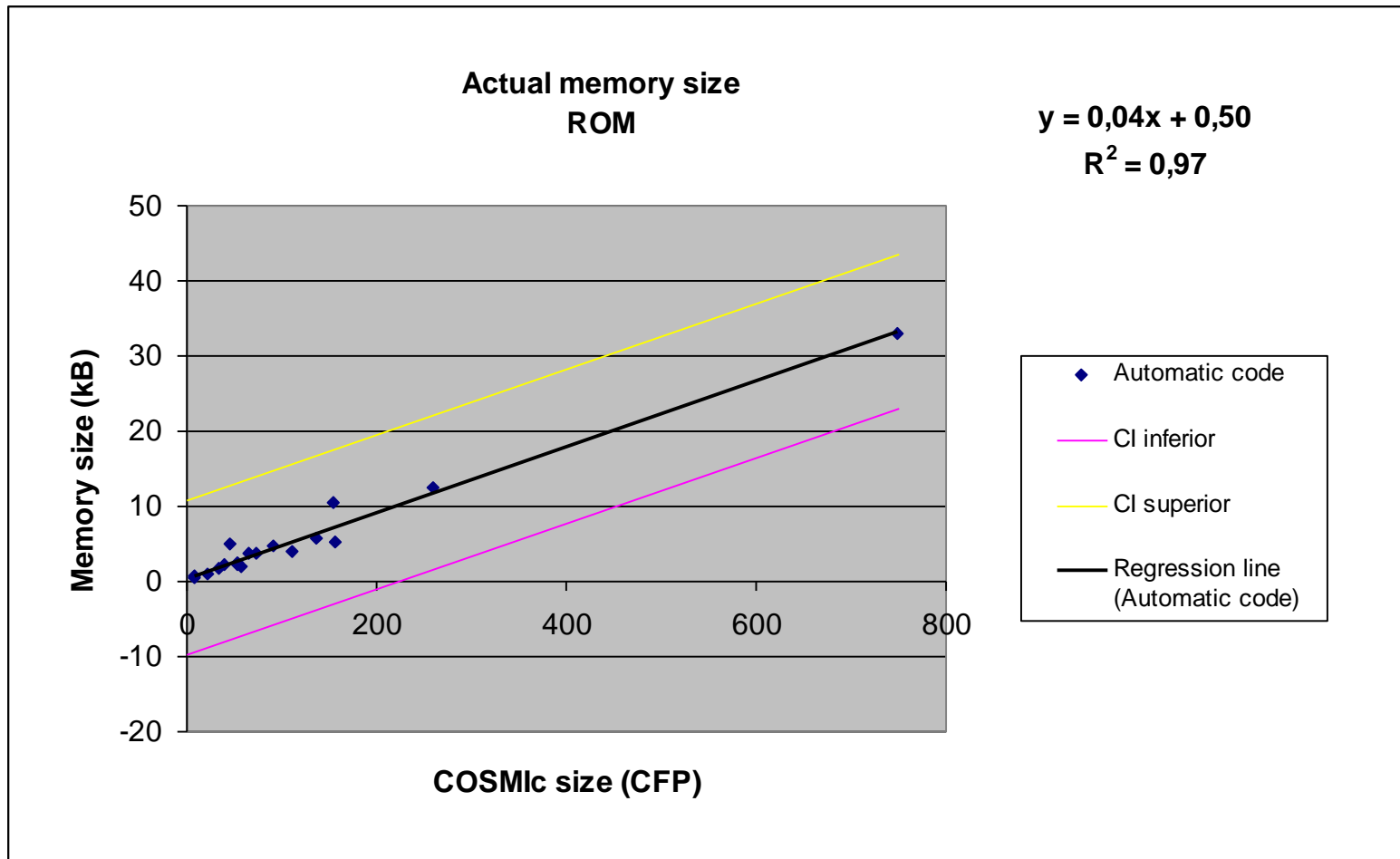


Fig 3. CFP vs ROM size (kB) (excluding the outlier)



Case Study (step 3)

Data Analysis

- **The memory size estimates obtained by expert opinion methods were compared to estimates obtained by the estimation model**



% Residuals for ROM, RAM and E2P Estimates

Statistics	% Residual (COSMIC)		% Residual (Renault Experts)		% Residual (Supplier Experts)
	ROM	RAM+ E2P	ROM	RAM	ROM
Min	-46.10%	-77.50%	-78.10%	-91.00%	-78.70%
Max	74.90%	214.20%	106.30%	1728.90%	1831.20%



Fig 4. Comparison between memory size estimates

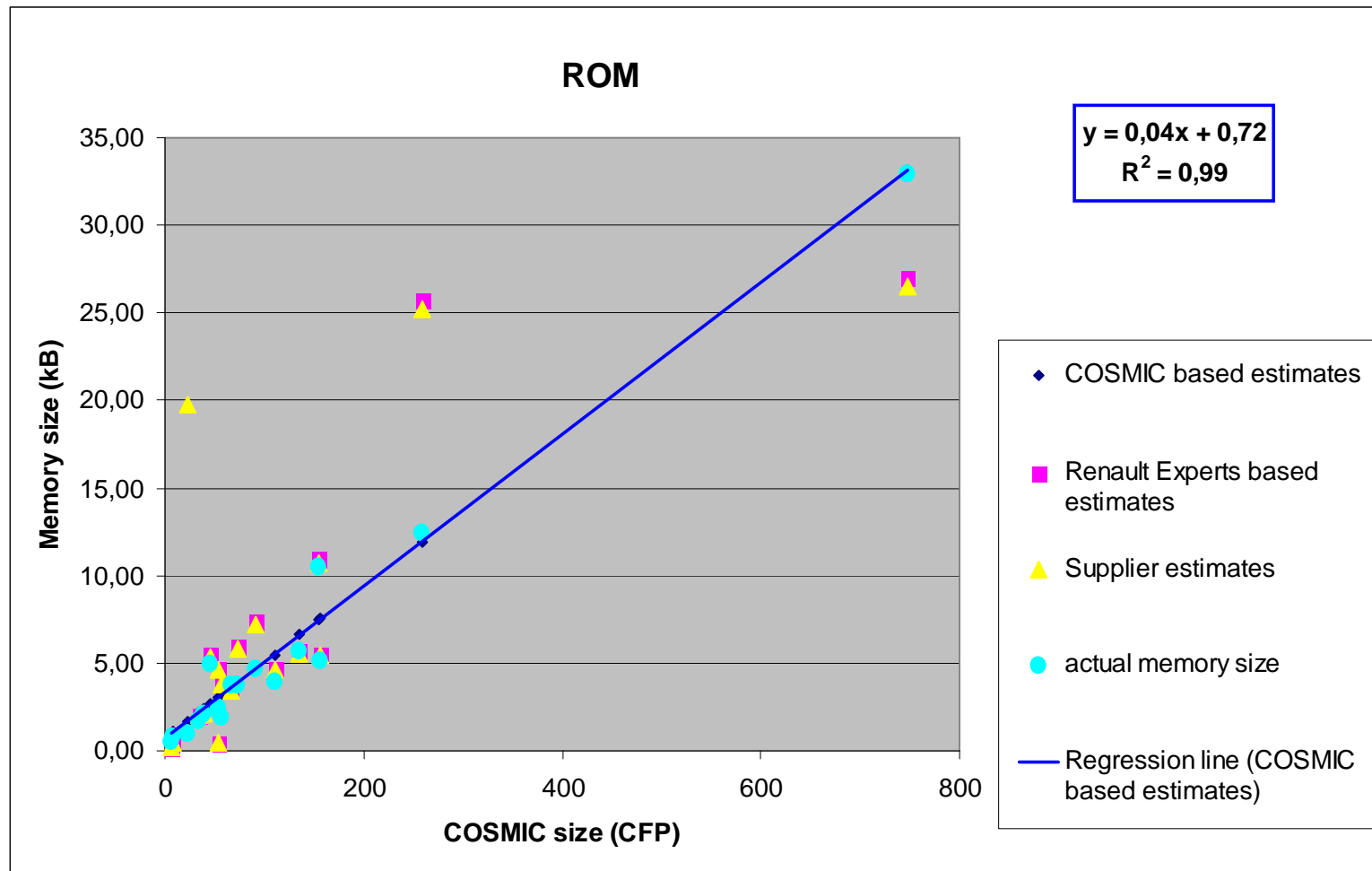
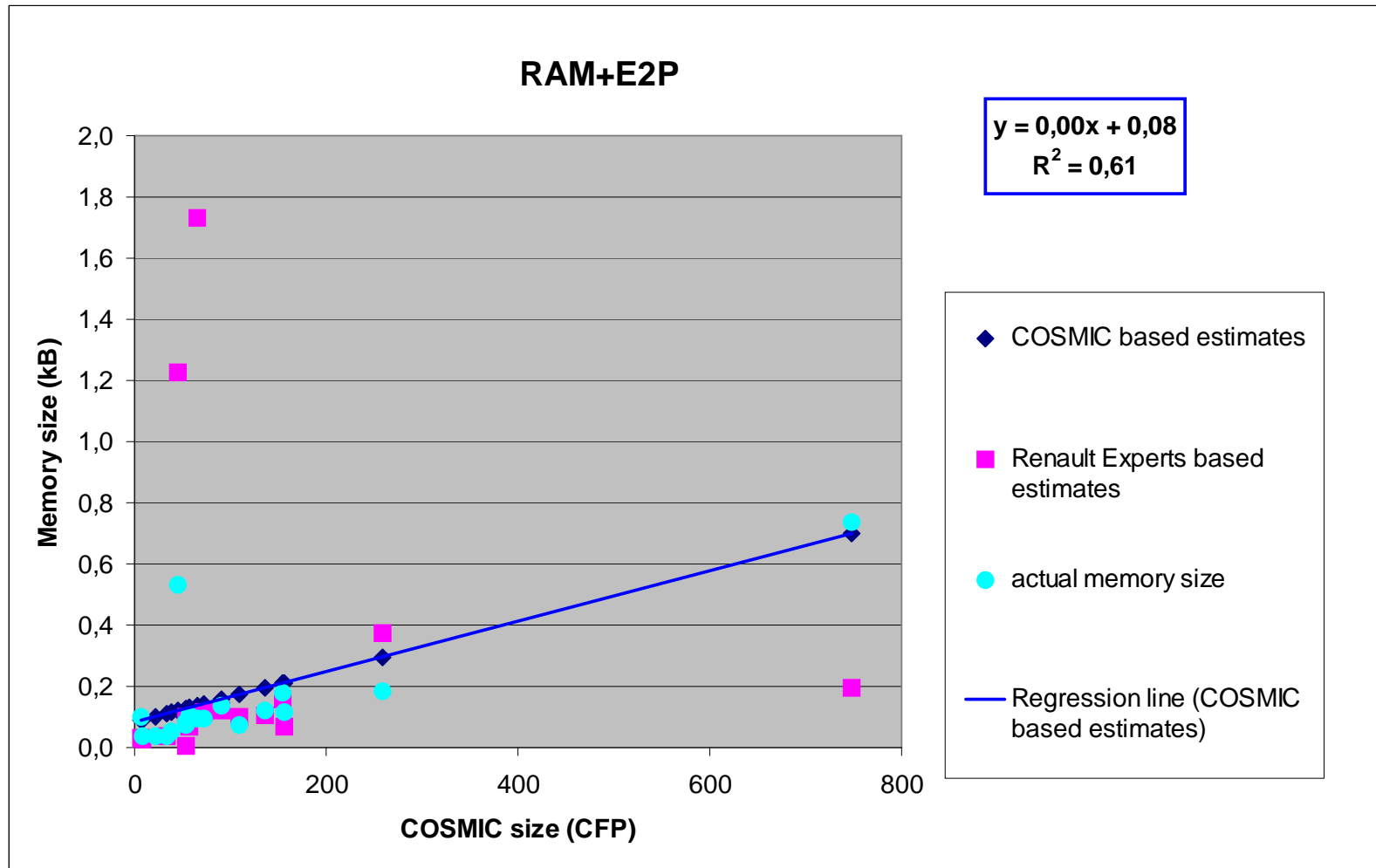


Fig 5. Comparison between memory size estimates



Conclusions for Renault

- After using the COSMIC functional size for software development costs estimations for more than two years → our results on memory sizes showed us that *COSMIC is a very good software metric.*
- Our goal is now to perform memory sizes estimations on future BCM, and to pursue studies on other ECUs.



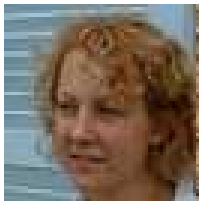
General conclusions

- **Our results confirmed the previous results obtained by Lind and Heldal that using CFP can be used for ECUs memory size estimation..**
- **This approach might be also beneficial for other types of embedded systems' memory size estimations (such as mobile phones, televisions, etc.)**



Thank you for your attention!

Questions ?



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