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Innovation and Chip Redesign to Address Semiconductor Shortages in the Automotive Industry

(and possibly enhance the strength of onshore production)

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In this paper we address the global semiconductor shortage and outline a critical path toward addressing that shortage through chip innovation and redesign.

The global semiconductor shortage holds the potential to adversely affect the economy and jobs, particularly in the automotive industry. While immediate shortages are likely temporary, they are indicative of broader underlying problems, including the U.S. government's lack of real-time situational awareness of semiconductor supply chains, the limited influence of certain industries and the military due to their small proportion of total demand, and the industry's reliance on foreign sources of supply in geographic areas likely to experience increasing turmoil in the near future.

Chips demanded by the automotive industry -- particularly companies like Ford and GM -- face challenges similar to those faced by the Department of Defense (DoD). Aerospace, auto, and medical devices are small percentages (auto 10-12%) of the total semiconductor market compared to cell phones and computers, and as a consequence can have less market power during shortages. Traditional internal combustion engine vehicles (in contrast to electric and autonomous vehicles) do not require the most advanced chips (which is both a strength and a weakness). Indeed, safety and reliability concerns make older, more reliable semiconductor nodes more attractive for production. Thus, while not using the most advanced chips can limit options, it can also be an opportunity. For example, the DoD has similar needs in terms of prioritizing safety and reliability over high performance , and trusted fabrication facilities in the U.S. likewise do not operate at the most advanced semiconductor nodes.

Chip Innovation and Redesign: A Role for Government

In the semiconductor industry, given the high capital costs and long lead times in building new fabrication facilities, it can be easier to redesign chips for existing production facilities than the other way around. The DoD has a long history of redesigning chips from legacy systems to be produced on available fabrication facilities. Analogously, there may be opportunities to redesign some automotive chips to be produced at onshore Intel, Global Foundries, or DoD fabs to circumvent some shortages. *This approach currently faces two bottlenecks, which the government may have a role in overcoming: lack of in-house knowledge in chip redesign by conventional automakers, and lack of available fab capacity at commercial (non-DOD), onshore production fabs.*

Lack of in-house knowledge in chip redesign by conventional automakers: While the auto companies have begun pursuing redesign opportunities, companies such as Ford and GM are limited by not having their own design teams in house. The DOD also does not have many in-house designers, but rather contracts out to the defense industrial base companies (e.g., Northrup, Boeing, BAE, etc.) for chip design. Thus, in the short term, external support from academia and DOD contractors through a public-private partnership, could help bridge the gap in chip design knowledge within auto companies. It would be important to understand how such an effort might interact with the recently-awarded RAMP-C project that seeks to build onshore chip design and fabrication infrastructure, which is now solely focused on DOD needs.

Lack of available fab capacity at commercial (non-DOD), onshore production fabs: A second challenge in pursuing chip redesign is the lack of onshore fabrication accessibility and capacity. While Intel strives to make their foundry services similar to companies like TSMC (Taiwan Semiconductor Manufacturing Corporation), they are disadvantaged by not having the necessary customer interface and support infrastructure. Because conventional vehicles produced by Ford and GM do not require the latest IC technology, appropriate facilities may already exist at fabs used by the DoD, which also do not require cutting-edge IC technology. As such, in parallel to efforts with Intel to build a foundry ecosystem, onshore capabilities leveraged by the DoD at GlobalFoundries, trusted fabrication facilities, and government laboratories may be important additional resources. To leverage these onshore DoD-focused facilities, government support would be essential because DoD and associated entities would have the best understanding of available capacity and capability at these facilities. Regardless of which fabs are used and when, leveraging onshore capacity could have important learning implications for other initiatives in the medium term.

A government role in facilitating and accelerating chip redesign: Importantly, while faster than changing an existing production facility or building a new one, chip redesign still has a 6-12 month lead time. If automakers seek to port a design from one IC technology to another (and not ask the fab to change their technology), this generally requires dozens of people and months of work. During this time, chip designers need to understand what to design, complete the actual re-design, execute initial fabrication and test/qualification on the re-designed chips, and then shift to volume production and eventual deployment. Going forward, how could the U.S. government spur innovation to make this faster and easier (e.g. cheaper)? Two technical routes are promising:

(1) *Facilitate use of reconfigurable solutions*. For some parts, reconfigurable solutions (such as FPGAs) may be able to quickly fill the current shortage by replacing unavailable ASICs. Since the acquisition of Altera in 2015, Intel is now a top-tier FPGA design and fabrication company. If an FPGA on an advanced node can be programmed to replace a custom designed ASIC on an older node, this provides a short term (although per unit more costly) stopgap solution for automakers. Here, the government's primary role, would be facilitating exploration of the feasibility of such a solution, and then if these units prove more costly and the automakers have low market share, short-term subsidies may be warranted to cover assessing compatibility of

existing chips, chip purchases, and any board or system redesign (ideal would be if none of the latter were needed).

(2) *Lower the cost of redesign for modern processes*. The typical approach to manufacturing on leading-edge processes is to couple the chip design tightly to the design rules for the process, to take advantage of every advantage the process offers and push the limits of what can be done in that manufacturing technology. This is, for example, how Intel approaches microprocessor manufacturing.

Legacy chips that merely need any available manufacturing capacity do not require such careful tuning. Unfortunately, there is a capability gap: The rules for which the legacy chips were designed will not work on cutting-edge processes, and so the automotive or other legacy designers may be forced to try to follow the leading-edge techniques, requiring excessive investment of time and design cost. An approach that can help here is to create generic design rules that can work (at some reduced efficiency) across a variety of process technologies, even those from different vendors. This approach is well suited for government support as it cuts across both chip manufacturers and generations of manufacturing technologies. Indeed, the US (primarily DARPA's Microsystems Technology Office) once funded the development of such rules, in the form of the Mosis SCMOS project, to create chips that were close to "fab-agnostic" (could be manufactured on a variety of different production lines). Unfortunately, this project has not been updated since roughly 2004. The need for such rules is more apparent today than it was even then, making funding to revitalize and update them all the more relevant.

Supply chain resilience — building not only for today by also the future: While an analysis of semiconductor chip redesign to circumvent could be pursued on its own, ideally it would be paired with real-time situational awareness of the current supply chain, and how we expect -- along with parallel industry and government policies to increase autonomy and vehicle electrification -- automotive industry demands for semiconductor chips (and thus the ideal chip redesign and associated supply chain strategy) can be expected to shift over time. A supply chain analysis could also be particularly important in the short to medium term if it revealed how shifts by too many firms (e.g., if aerospace, automotive, and medical devices all shifted) might create new problems. Finally, such real-time situational awareness will help inform federal research and innovation investments in the emergent microelectronics initiative.

Real-time Situational Awareness — filling in critical missing data from public sources: Finally, building real-time situational awareness in semiconductors for supply chain analyses has value on its own, particularly from a third party neutral source. Today, semiconductor plant data is not all in one place: SEMI has SEMI Fab database with production and capacity data on over 1000 fabs and the OSAT manufacturing sites database with over 360 packaging production locations. VLSI and SIA both have plant utilization data. Data on second and third tier suppliers, however, is poor, and while plant capabilities are tracked, information on actual plant capacity is lacking (capacities in the SEMI fab database is estimated by analysts), as is any product-level information on the number of wafers produced or the number of devices produced (or the proportion of each device). Here, natural language processing and machine learning of public information - seeded by government and commercial SCRM teams - could make important inroads on second and third tier suppliers, as well as product-level capacity information. In turn, techno-economic analyses of how technology (material, process, and design) change could influence plant-level operations and capacity offer the potential to provide important forward-looking capabilities to supply chain models, as well as to inform government on the value of innovations in particular areas and to inform commercial investment strategies both in innovation and in capacity. On the demand side, it is difficult for relatively smaller (compared to cell phones and computers) sources of semiconductor demand like the automotive, aerospace, and medical device industries to know how simultaneous actions could create further problems. Here, the integration of real-time situational awareness, forward-looking techno-economic and supply chain capabilities will provide essential tools to avoid future economy-stopping supply chain bottlenecks -- both through advanced capacity and innovation.

Critical path toward the most immediate chip innovation and redesign solution:

1. Engage independent entity aggregate and analyze data across
    - key **technical** players from the automotive manufacturers (GM, Ford);
    - available chip re-design capabilities (Northrup, Boeing, BAE systems), and
    - available foundries (Intel, GlobalFoundries, DOD trusted foundries).

… to answer the following questions:

a. What domestic fab capability is available, both in the commercial space - such as at Intel and GlobalFoundries - and in the more specialty spaces (e.g., DOD trusted fabs, national lab fabs, etc.)? What would need to be accomplished in the business and policy arenas to harness that capability?
b. What design capacity is available both in the commercial space (Northrup, Boeing, BAE systems, intelligence community) and in academic contexts.
c. Assuming that there is sufficient capacity in (a) to do something useful, how technically would that get accomplished?

2. After this aggregation of data and analyses, the analyses should be presented individually to key players, and then used by the government to spur paths forward.

References

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The Carnegie Mellon University Team's Approach to the Semiconductor Shortage

1. Could relaxed/agnostic re-design leverage non-traditional onshore capacity such as defense, national labs, etc.? Could reconfigurable solutions be used as stopgap replacements for low-availability ASICs?
   CMU Leads = ECE: Ken Mai with Shawn Blanton and Larry Pileggi
   a. What is the short-term (next few months), medium term (next few years), versus long term (given changes in chip demand given vehicle electrification and automation) solution?
   b. How would short, medium, and long-term reconfiguration options change supply chain dynamics?

Lead Agency: Collaboration between Industry, DOD, and Commerce, led by OSTP. May require a PPP with individual contracts with automotive manufacturers with a mechanism to inform actions by Commerce and the DOD.

2. Why do we have this situation? (e.g. How did pandemic shift set this shortage off?)
   Lead = Heinz: Ramayya Krishnan with Peter Zhang (support from faculty in 1 and 3)
   a. What was the shift in product mix (possibly to be provided by BIS and Financial statements) during the pandemic that potentially led to mis-estimations of demand?
   b. How do we better prepare for a variety of potential future shocks? E,g, How does retargeting design and onshore capacity gain us flexibility for such situations in the future? What else might gain us additional flexibility?

   Lead agency: Commerce

3. What are the security risks of offshore capacity? What are our known constraints, what are our known unknowns (e.g. tier 2 and tier 3 suppliers)?
   Lead = LTI / MLD: Ed Hovy, support from Ankit Dangi
   a. Data: Seed data from SEMI and SIA; expanded datasets from Commerce; expert knowledge from supply chain risk teams in government and companies; fill in missing information with public scraping and NLP

   Lead Agency: DARPA, DOD; in partnership with industry; should include partnership with supply chain risk teams in government (MITRE) and companies.

Information that would need to be available to a Public Private Partnership

I. What are the exact types of shortages? What would the feasible solution space look like?

1. What parts are you missing?
2. Part type (e.g., microcontroller, sensor, etc.)
3. Part source (e.g., Renesas)
4. Part manufacturer (i.e., fab) and process node
5. Part price
6. Part robustness classification (e.g., consumer, milspec, etc.)
7. Part qualification requirements
8. Lead time for manufacture/purchase
9. Number of parts used per system
10. Number of systems manufactured per day

II. What are available capabilities at onshore DOD facilities. Is there excess capacity? How do these match up to automotive supplier needs?

III. How are automotive industry's semiconductor needs expected to evolve in the short (next three months), medium (next two years), and long term (5-10 years)?

Important Partners and Collaborators

Commercial Partners (* = most relevant):

- Automotive OEMS (*): GM, Ford
- Commercial Onshore Foundries Intel, Global Foundries (*)
- Defense Contractors (*): Northrup, Lockheed, Boeing, BAE Systems
- Defense Trusted Foundries (*)
- Existing automaker chip suppliers: Delphi, ST Micro, NXP, ON Semiconductor
- Industry and Worker Associations: United Automotive Workers Union (UAW), Semiconductor Industry Association

Government Programs:

- Department of Commerce (*)
- Department of Defense (*)
- DARPA Microsystems Technology Office (*), Information Innovation Office
- https://www.cisa.gov/supply-chain a govt agency that engages in 'detective' work when a new threat/risk is uncovered (for example, suspected espionage in a factory).